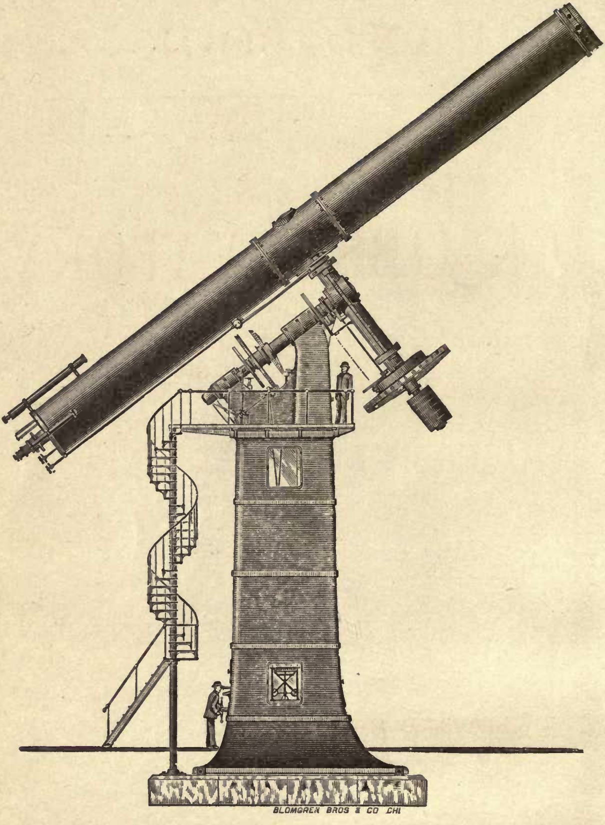
HAND-BOOK

OF THE

LICK OBSERVATORY

EDWARD S. HOLDEN, LL. D.
(Director of the Lick Observatory)



THE GREAT TELESCOPE

From the original design of Warner & Swasey, makers of the mounting
The tube is 57 feet long and is 4 feet in diameter at the centre. The objective by Alvan Clark & Sons, is 36 inches in diameter.
The highest magnifying power is 3360 diameter;
the lowest 180 diameter.

HAND-BOOK

OF THE

LICK OBSERVATORY

OF THE

UNIVERSITY OF CALIFORNIA.

BY

EDWARD S. HOLDEN, LL.D.,

Director of the Observatory.

SAN FRANCISCO:
THE BANCROFT COMPANY

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I. INFORMATION FOR INTENDING VISITORS.

Hotels in San Jose: It may be necessary for visitors to pass the night in San José. Omnibuses from each hotel meet all railway trains. Good accommodations may be had at the

St. James' Hotel: Rooms and board at $2 to $2.50 per day.

Stage Lines: The stages of the Mount Hamilton Stage Co., are large, roomy and very comfortable, open on the sides so that an extensive view of the surrounding country can be had at all times; the drivers are courteous, and instructed to furnish patrons with information regarding points of interest; frequent change of horses will take visitors through in quick time. Procure your seats of the Agent at office of Wells, Fargo & Co., San Jose, the night before. Stages start out at 7:30 A. M. You will find the mountain drive itself, in the elegant turnouts of the Mount Hamilton Stage Co., well worth the visit to the Summit; it is old time California Staging on an improved plan, and this drive is destined to be a feature of itself to tourists visiting the observatory, as there are no conveniences for a change of horses on the route, and the distance so great, we would advise tourists to avoid private conveyances.

Telephone Messages: The private telephone line of the observatory is connected with the Central Office in San Jose and there are several stations along the road to Mt. Hamilton (which the driver will know).

In any case of doubt as to whether the Observatory is open to visitors at a particular time, etc., it is better to telephone to Mt. Hamilton and receive an answer. The Observatory rules are very liberal in regard to the reception of visitors and for that very reason they are rigidly adhered to, in order that equal rights may be secured to each person, where all are equally interested.

Photographs: Of the Observatory and of the scenery along the road are on sale at LORYEA & MACAULEY'S, W. D. ALLISON'S, and other places in San José, and at TABER'S, 8 Montgomery street, H. A. MATHEWS', 331 Montgomery street, and other places in San Francisco.

Dress: The summer days are apt to be hot and dusty, and a long linen duster is almost essential. Tie a handkerchief around your neck if there is much dust. In the early mornings of spring and fall a light overcoat is required.

Shooting on the Reservation: The Regents of the University have caused the following to be posted:

NOTICE.

> "This is a reservation for Observatory uses only. No unauthorized hunting or shooting is permitted. No notices or advertisements are to be posted on the Reservation, or painted on the rocks without authority. Horses, cattle and sheep must not be allowed to run at large.
>
> By order of the Committee of the Board of Regents of the University of California on Grounds and Buildings.
>
> J. WEST MARTIN, Chairman."

HOURS FOR VISITORS TO THE LICK OBSERVATORY.

The Board of Regents of the University of California has established the following regulations, which have been conspicuously posted in various places. The orders of the Board will be strictly obeyed:

"VISITORS will be received at the Lick Observatory during office hours, whenever any of the astronomers are present.

Regular nights in each month, not exceeding one per week, shall be set apart for the reception of visitors, except during inclement weather, and visitors will be received on these nights between certain hours *and at no other times.*"

By order of the BOARD OF REGENTS,

Until further notice, the Observatory will be open to visitors daily except Sunday, from 10 A. M. to 4 P. M., and on Saturday nights from 7 to 10 P. M. *There are no hotel accommodations on the summit.*

The following circular has also been widely distributed and will be mailed to any person applying for it.

[CIRCULAR.]

Hours for Visitors to the Lick Observatory: The Observatory Buildings will be open to visitors during office hours, every day in the year. Upon their arrival, visitors will please go at once to the Visitors' Room and register their names.

An hour or so can be profitably occupied in viewing the different instruments, and the rest of the stay can be well spent in walks to the various reservoirs, from which magnificent views of the surrounding country can be had. At least an hour and a half of daylight should be allowed for the drive from the Summit to Smith Creek. *There are no hotel accommodations at the Summit.*

ADMISSION OF VISITORS AT NIGHT.

For the present, visitors will be received at the Observatory to look through the great telescope every Saturday night, between the hours of 7 and 10, and *at these times only.*

Whenever the work of the Observatory will allow, other telescopes will also be put at the disposition of visitors on Saturdays between the same hours (only).

At 10 P. M. the Observatory will be closed to visitors, who should provide their own conveyance to Smith Creek, as there is no way of lodging them on the mountain.

It is expected by setting apart these times for visitors (which allow freer access to the Lick Observatory than is allowed to any other observatory in the world) that all interested may be able to arrange their visits in conformity to them; and that the remaining hours of the week will be kept entirely uninterrupted, in order that the Astronomers may do the work upon which the reputation and the good name of the Observatory entirely depends.

VISITORS' NIGHT.

I may be allowed to quote here a paragraph from a public announcement in regard to our visitors' nights, which I made in 1886. It will serve to indicate how these evenings are to be spent.

"We shall regularly appoint in each one of the favorable summer months certain evenings for the reception of visitors to look through the telescopes. We shall usually have three telescopes available for this purpose—a 6-inch, a 12-inch and the 36-inch equatorial. These will each be under the charge of an astronomer, and each will be kept directed at a different object in the sky. The visitor will be shown through the various buildings, and will see the various instruments and will hear their various uses described. With these three telescopes he can see three different and interesting objects, as the moon, a binary star, a nebula, and in a short time he can gain some individual and real knowledge concerning the heavenly bodies, of which he has read and studied, and obtain some insight that will be new to him.

The visitors' nights will be strictly devoted to these ends: the whole force of the observatory will be employed to making them useful, interesting and pleasant to our guests. Not only will visitors be welcome on these special nights, but they will always be welcome during the daylight hours. The observatory is always open in the daytime during office hours, and at certain times of the day, visitors will be personally conducted through the various rooms.

In return for this free access, we confidently expect the citizens of California to jealously guard for us the other nights of the month, and to see to it that these other nights are strictly reserved for purely astronomical uses, and to the prosecution of strictly scientific work. I feel entirely sure, when it is known how imperatively necessary it is, in order that any valuable discoveries shall be made, that the whole attention of the astronomer shall be concentrated upon his work, with no interruptions and no distractions, that we shall have the loyal assistance of all in preserving for us that freedom. This is an important point to be well understood in the beginning. The observatory fully recognizes its duty to the community, and it allows the freest access of any institution of like character in the world. It also fully recognizes that it is primarily here to advance the science of astronomy, and that unless it does so, the large telescope had better be given to some observatory that will do this, and the buildings and grounds be turned over to the State for a public park. I think the arrangement suggested will be all that can be needed. It provides not only for the advancement of knowledge, but for its diffusion. Remember how many thousands of visitors to California there are, and how few nights there are in a year, and see to it that your astronomers have all the time they need."

General Remarks: Be sure to have your driver point out to you the objects of interest along the road. Where there is so much to see, you may easily miss something worth remembering. If you will glance over the subsequent parts of this Hand-Book, reading the paragraphs that interest you, it may serve to call your attention to a view or to a fact that you would wish not to pass by unnoticed.

On your arrival at the observatory, register your name and address in the Visitors' Room.

Visitors' Room: A room has been set apart in the observatory for the use of visitors, and comfortably furnished. A dressing room (for ladies only) opens from it, and is provided with fresh water, towels, soap, etc.

A lavatory for men opens from the long hall.

It is not allowed to take luncheon in the Visitors' Room.

If no one is present to receive you, pull the janitor's bell in the room.

The Secretary's office is immediately across the hall.

Visitors are especially requested not to touch or handle any of the astronomical or other instruments. An idle touch may disturb an accurate adjustment which it has required hours to make. Opening a door with *No Admittance* upon it may ruin a set of photographic plates which cannot be replaced.

No books should be removed from the library shelves. Most of them are not especially rare, but they cannot be replaced on this side of the Atlantic.

Near many of the instruments is a little printed sign giving the chief facts regarding it. All desired information can frequently be had by consulting this. The janitor or, in his absence, the Secretary will be glad to answer all questions.

Finally, recollect that it will be a pleasure to each one of the officers and employés of the observatory to do everything that may be needed to make your visit pleasant. Remember, however, that their time belongs to science and to the State, and do not ask any unreasonable amount of their attention without good cause.

JAMES LICK

Born 1796 - Died 1876

FOUNDER OF THE LICK OBSERVATORY

II. SKETCH OF THE LIFE OF JAMES LICK.

JAMES LICK was born in Fredericksburg, Pennsylvania, August 25th, 1796, and died in San Francisco, October 1, 1876. He learned and practised the trade of organ and piano making in Hanover, Pennsylvania and in Baltimore. In 1820 he was in business in Philadelphia. From there he went to Buenos Ayres, making and selling pianos. From the east coast of South America he came to the west, and finally in 1847 he drifted to San Francisco.

Successful in business but far more suceessful in his investments in land he became rich and died, leaving an estate of some $3,000,000. This was all devoted to public uses His deed of trust charged the Board of LICK Trustees to expend :—

For a monument in San Francisco to FRANCIS SCOTT KEY (author of the Star Spangled Banner) the sum of $60,000. This monument has been made by the celebrated American sculptor WILLIAM W. STORY and it will be erected in Golden Gate Park on July 4, 1888.

For statuary to be placed in front of the San Francisco City Hall and to be emblematic of three significant epochs in the history of the State of California, $100,000.

For a Home for Old Ladies in San Francisco, $100,000.

For Free Baths in San Francisco, $150,000.

For a California Institute of Mechanic Arts—a manual training school for the boys and girls of San Francisco, $540,000.

For the Lick Observatory, to contain the most powerful telescope in the world, $700,000, besides many other important bequests, to the Society of California Pioneers, to the California Academy of Sciences and other beneficiaries.

His exact provisions in regard to the Observatory were :—

EXTRACT FROM MR. LICK'S SECOND DEED OF TRUST. (SEPT. 21, 1875.)

Third—To expend the sum of seven hundred thousand dollars ($700,000) for the purpose of purchasing land, and constructing and putting up on such land as shall be designated by the party of the first part, a powerful telescope superior to and more powerful than any telescope yet made, with all the machinery appertaining thereto and appropriately connected therewith, or that is necessary and convenient to the most powerful telescope now in use, or suited to one more powerful than any yet constructed; and also a suitable observatory connected therewith. The parties of the second part hereto, and their successors, shall, as soon as said telescope and observatory are constructed, convey the land whereupon the same may

be situated, and the telescope, and the observatory, and all the machinery and apparatus connected therewith, to the corporation known as the 'Regents of the University of California;' and if, after the construction of said telescope and observatory, there shall remain of said seven hundred thousand dollars in gold coin any surplus, the said parties of the second part shall turn over such surplus to said corporation, to be invested by it in bonds of the United States, or of the City and County of San Francisco, or other good and safe interest-bearing bonds, and the income thereof shall be devoted to the maintenance of said telescope and the observatory connected therewith, *and shall be made useful in promoting science;* and the said telescope and observatory are to be known as 'the Lick Astronomical Department of the University of California.'"

Of all of Mr. LICK's gifts that one which will be most widely known and in a large sense, most widely useful, is the gift of the Astronomical Observatory which bears his name.

It will never be known exactly how Mr. LICK finally decided upon the construction of the observatory which bears his name. He was an assiduous reader, and among his favorite books were those of ANDREW JACKSON DAVIS which like EDGAR POE'S *Eureka,* present a cosmogony more poetic than veracious. It is possible that his thoughts were turned to astronomy by these books.

It would be of extreme interest if one could give a truly adequate view of the character of Mr. LICK, and of the motives which led him to dispose of his large fortune in public gifts, and especially of the motives which led him to found an astronomical observatory.

Certainly, no sufficient exposition of either his character or of his motives has yet appeared in print. There is no doubt that a desire to be remembered by his fellow-men influenced him largely. He wished to do something which should be important in itself, and which should be done in a way to strike the imagination. He was only restrained from building a marble pyramid larger than that of CHEOPS on the shores of San Francisco Bay, by the fear that in some future war the pyramid might perish in a possible bombardment of the place. The observatory took the place of the pyramid. The beauty of the one was to find a substitute in the scientific use of the other. The instruments were to be so large that new and striking discoveries were to follow inevitably, and, if possible, living beings on the surface of the moon were to be described, as a beginning.

It would, however, be a gross error to take these wild imaginings as a complete index of his strange character. A very extensive course of reading had fixed in him the generous idea that the future well-being of the race was the object for a good man to strive to forward. Towards the end of his life at least, the utter futility of his money to give any inner satisfaction oppressed him more and more. The generous impulses and half-acknowledged enthusiasms

of earlier days began to quicken, and the eccentric and unsymmetrically developed mind gave strange forms to these desires. If he had lived to carry out his own plans, his fellow citizens might have gained less from his gifts than they will now gain. If his really powerful mind could have received a symmetric training, there is no question but that the present disposition of his endowment would entirely satisfy him.

He has been most fortunate in having his desires studied and given an ultimate form by successive sets of trustees, who had no ends in view but to make this strangely acquired gift most useful to the city, the State, and the country. He is buried in the base of the pier of the great equatorial on Mount Hamilton, and has such a tomb as no old-world emperor could have commanded or imagined.

REMOVAL OF MR. LICK'S REMAINS TO MOUNT HAMILTON.

Mr. LICK several times expressed his desire to be buried at Mount Hamilton near his great observatory when it should be complete. During the summer of 1886 the brick foundation for the iron pier of the great equatorial was built by Mr. FRASER and a suitable vault was prepared directly under the spot where the great telescope was to be and now is. In January 1887 the Lick Trustees invited a number of representative gentlemen to act as an escort of honor during the transfer of Mr. LICK's remains from their temporary resting place in San Francisco to their final tomb on Mount Hamilton.

At San José the *cortège* was met by a delegation of citizens headed by the Mayor of the city; and the coffin was transferred from the cars to a mountain-wagon, and covered by the star spangled banner. Mr. FRASER, who had been Mr. LICK's confidential man of business, and who was then Superintendent of Construction, conducted this wagon in the lead; and the body was followed by the escort.

At the observatory, the procession was met by Captain FLOYD, the President of the Trustees, and after a simple and impressive ceremony the coffin was opened, the remains identified, and the casket sealed within a leaden case and cemented beneath the massive blocks of stone which form the foundation of the great telescope which Mr. LICK has given to his fellow citizens.

Before the close of the ceremonies Professor GEORGE DAVIDSON, President of the California Academy of Sciences, read to the escort and had signed by them, the following admirable *document of identification* which had been drawn up by him.

This document was engrossed on parchment, placed between two fine tanned skins backed with silk, placed again between two leaden plates, soldered securely in a tin box, and finally deposited within the coffin itself.

DOCUMENT OF IDENTIFICATION.

This is the body of

JAMES LICK,

who was born in Fredericksburg, Penn., August 25, 1796, and who died in San Francisco, Cal., October 1, 1876.

It has been identified by us and in our presence has been sealed up and deposited in *this Foundation Pier of the*

GREAT EQUATORIAL TELESCOPE

this ninth day of January, 1887.

In the year 1875 he executed a *Deed of Trust of his Entire Estate* by which he provided for the *Comfort and Culture of the Citizens of California;* for the *Advancement of Handcraft* and *Rede-craft* among the *Youth of San Francisco* and of the *State;* for the *Development of Scientific Research* and the *Diffusion of Knowledge* among *Men* and for

FOUNDING IN THE STATE OF CALIFORNIA AN ASTRONOMICAL OBSERVATORY TO SURPASS ALL OTHERS EXISTING IN THE WORLD AT THIS EPOCH.

This observatory has been erected by the Trustees of his estate, and has been named

THE LICK ASTRONOMICAL DEPARTMENT OF THE UNIVERSITY OF CALIFORNIA

in memory of the founder.

This refracting telescope is the largest which has ever been constructed and the astronomers who have tested it declare that its performance surpasses that of all other telescopes. The two discs of glass for the objective were cast by CH. FEIL of France and were wrought to a true figure by ALVAN CLARK & SONS of Massachusetts. Their diameter is thirty-six inches and their focal length is fifty-six feet two inches.

Upon the completion of this structure the Regents of the University of California become the *Trustees of this Astronomical Observatory.*

[Signed:] The Board of Trustees of the Lick Estate,

RICHARD S. FLOYD, President,
E. B. MASTICK,
CHARLES M. PLUM,
GEORGE SCHONWALD,

The President of the Board of Regents of the University of California and Governor of the State of California,

WASHINGTON BARTLETT,
(By J. W. WINANS.)

The President of the University of California and Director of the Observatory,

EDWARD SINGLETON HOLDEN,

The President of the California Academy of Sciences and of the Council thereof,

GEORGE DAVIDSON,

The President of the Board of Trustees of the California Academy of Sciences,

GEORGE E. GRAY,

The President of the Society of California Pioneers,

GUSTAVE REIS,

A Director and ex-President of the Society of California Pioneers,

PETER DEAN,

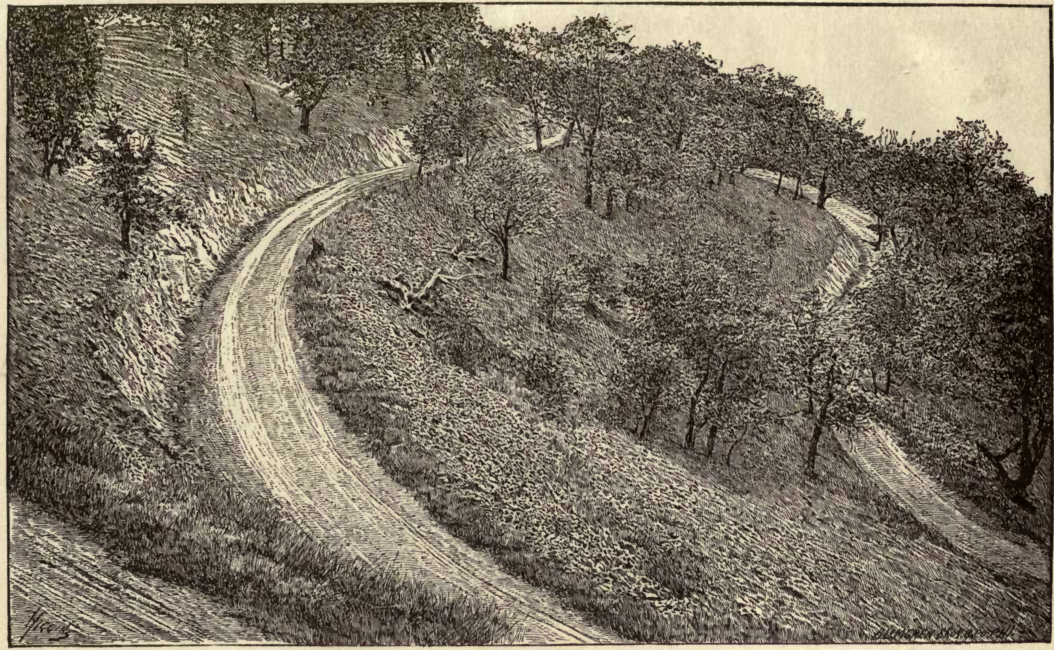
The Mayor of the City of San José,

C. W. BREYFOGLE.

The base of the great pier bears a simple bronze tablet with the inscription

HERE LIES THE BODY OF
JAMES LICK.

His true monument is the Observatory which he reared, and his lasting memorial will be the results of those astronomical observations which his generosity has instituted and endowed.



PART OF THE MOUNTAIN ROAD SHOWING TWO OF ITS 365 TURNS.
(Photographed by Mathews.)

III. A VISIT TO MOUNT HAMILTON.

Drive from San José to the Summit of Mount Hamilton: The regular stages for the Lick Observatory depart from San José about half-past seven in the morning in order to have a long day before the tourist. The straight, level avenue leaves the central square of the pretty and prosperous city and makes straight for the foothills, some four miles distant. On the left hand (north) are the sloughs of the Bay of San Francisco shining in the sun; on the right hand are beautiful, fertile fields. At the end of the four miles we are 300 feet above San José, and we begin the ascent of the Contra Costa range of hills, which border the exquisite Valley of Santa Clara on the east.

The road is built so that the grade is always kept less than six and a half feet in the hundred (343 to the mile). This maximum grade is only occasionally met in the first portions of the twenty-six miles, while the last seven miles have an average grade of nearly 300 feet per mile. In order to keep the gradient as low as this the thirteen miles of distance in an air line is made into twenty-six by the road, which follows the contours of the hillsides, turning into each ravine, following this to its head, and returning on itself along the opposite side. From the time that the ascent is commenced every moment is full of interest, for in all California there is no mountain road more delightful than this. The descent of St. Helena mountain into Napa Valley and the drive over the summit of the Santa Cruz range from Saratoga to Santa Cruz are the only ones which I know of in the State which can compare with it.

Finally we have climbed the side of the first range of hills and rest for a moment at the Grand View House (1,500 feet above the sea) before we turn sharply eastward towards the divide (1,838 feet) which separates the Santa Clara Valley from a small interior basin known as Hall's Valley. Before we leave this stopping place we should turn our faces towards San José and see how it lies in its lovely valley and mark the dark summit of *Loma Prieta* (Spanish for Black mountain) which is 3,790 feet high and 30 miles distant. This is the highest peak of the Santa Cruz mountains and its great dome is a landmark for miles and miles. Mt. Choual (3,500 feet) is next north of it and then comes Mt. Thayer (3,550 feet.) We shall see these mountains again from the summit of Mt. Hamilton which is plainly visible right before us. We descend rapidly into Hall's Valley (1,544 feet) along a beautiful road and past some magnificent

oaks, and again commence an ascent and reach a stopping place in the journey at the Smith Creek Hotel at the very foot of the mountain (2,146 feet above the sea.) Here is a comfortable country hotel and here is the last place on the road where an inn can be found.

The only buildings on the summit are those of the observatory proper, and the private dwellings of the astronomers. There is no hotel on the summit; only a visitors' room, in which there are lavatories where the tired traveler can remove the dust from his face and rest a moment after the long though interesting drive. Those who wish to look through the large telescope on the public nights (every Saturday evening from 7 to 10) must secure rooms at the Smith Creek Hotel; for at 10 o'clock the observatory is closed to visitors who have to return to Smith Creek for a lodging, leaving the astronomers to finish the night in their regular avocation of "minding the heavens."

At Smith Creek we are still 2,152 feet below the summit and we have still seven miles to go. The grade is heavy, and even with a good team an hour and a half is required for the ascent. The road is full of turns and twists and the scenery is rugged and wilder, though the beautiful trees relieve its hard outlines. The observatory buildings and especially the great seventy-five-foot dome seem to be directly above us, though each successive mile hardly seems to bring us nearer. Those of us who are vigorous and enterprising get out at the "flat" where the brick-kilns stand and walk up the trail to the summit. The sage ones remain in the wagon and do not lose their breath and have more leisure to view the magnificent hills and deed gorges and cañons on all sides of the way.

Finally the stage winds round the base of Mt. Ptolemy, named after the great astronomer of Greece, and emerges just south of the shining white Dome which we have seen for so long. A few words of encouragement to the horses and directly we have passed completely round the base of Observatory Peak (Mt. Hamilton) and come to the narrow saddle where the Astronomers' cottages lie nestled against the side of the mountain. We make a complete turn about the summit passing once more directly beneath the white Dome and then up to the summit-level and draw up before the western entrance to the building and alight. Here a sign tells us to ring the visitors' bell and the Janitor admits us and shows us to the visitors' room. The routine of the establishment requires us to register our names and addresses in a large book; and after this is done and the dust removed from our faces, we are ready to look about us and to see what manner of thing it is which the busy hand of man has builded on the summit of these splendid hills.

From the roof of the building we can see all around the horizon, and we begin to get a connected idea of the great topographic features. First we look back over the tortuous road that we have just left and see where the Santa Clara Valley and San José lie

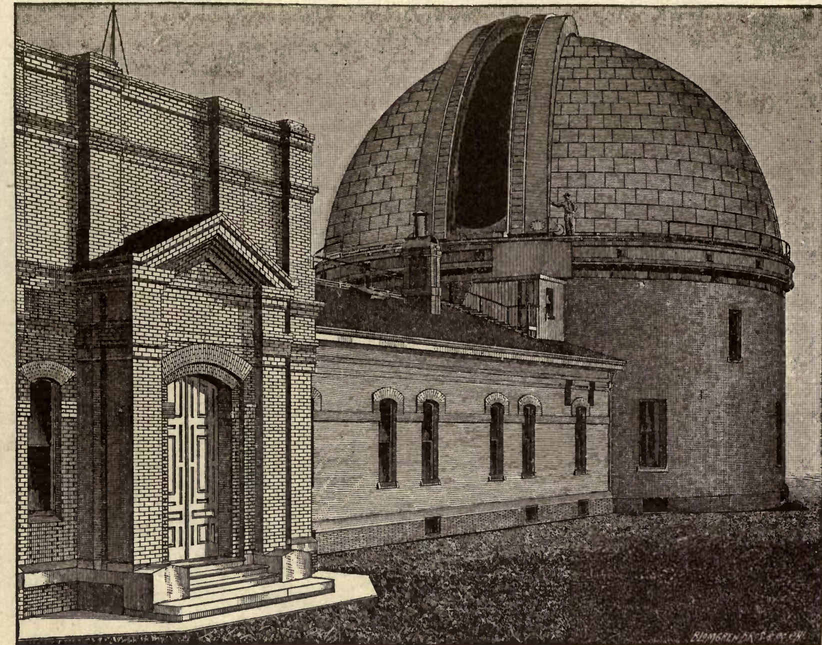
towards the West. *Tamalpais* (66 miles distant, 2,600 feet high) is plainly visible, and we know that the restless tides of the Golden Gate bathe his feet. Between us and *Tamalpais* we see first the arms of San Francisco Bay, then a range of summits (Mts. Story, Lewis, and Day, counting from west towards north.)

On the hither side of these summits is the deep and wild cañon of Smith's Creek which breaks through the mountains here on its way to join the Calaveras and to pour its waters into the Bay. Some day or another a large part of the water supply of San Francisco must be gathered here. Just over this cañon we see the symmetrical cone of *Monte Diablo* (39 miles distant and 3,849 feet high) in the north west. Immediately below us on the north is a deep black cañon (*Canon Negro*) which seems to join that of Smith Creek. Looking across it we see a high mountain (Mt. Galileo) about a mile away. Along its flank we can trace the winding road which leads to the springs and reservoir (*Aquarius*) which supply the observatory. They are 340 feet below us. A narrow saddle connects Galileo with Mt. Copernicus (4,380 feet high, 4,450 feet distant by the road).

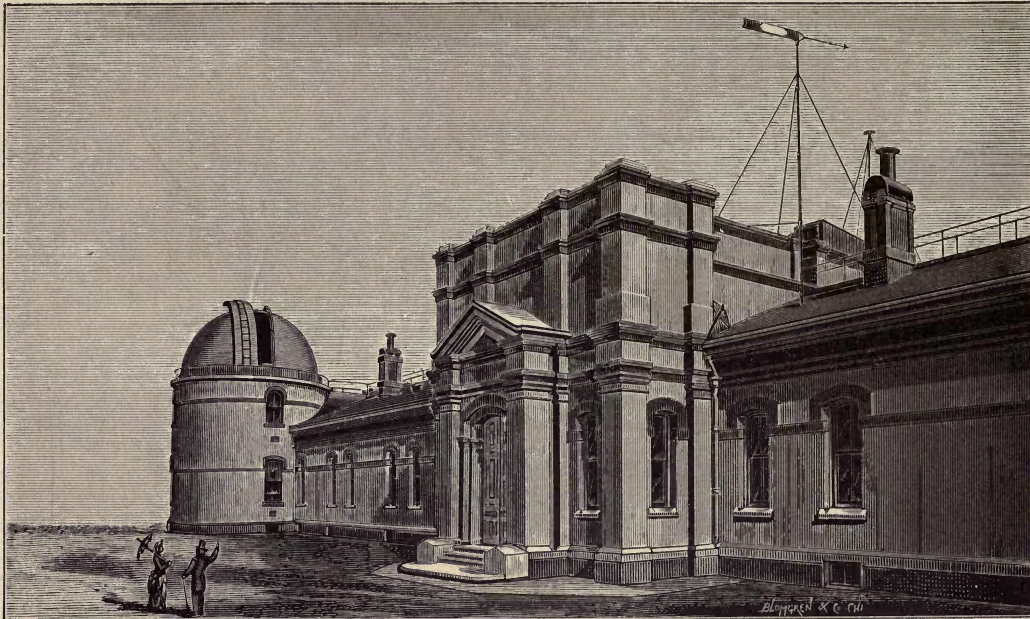
There is a high service reservoir on its summit, 171 feet above the observatory floor (which itself is 4,209 feet above the sea.)

We are now looking northeast. Still further to the east is Mt. Kepler (4,257 feet), also crowned with a reservoir. Between Copernicus and Kepler is a distant peak, Mt. Hipparchus, named after the father of Greek astronomy. To the right of Kepler and a mile or so distant rises the huge form of Mt. Santa Isabel (so named by the Spaniards) with a profound cañon separating it from us. Just below us, on the hither side of the cañon, is Mt. Huyghens with a third reservoir and a windmill on its summit. Between Kepler and Isabel lies the rugged San Anton Valley, used for a cattle ranch. Beyond it, rising in divide after divide, are the ranges of mountains which border the San Joaquin Valley on the west. The highest of these is Mt. Oso (3,363 feet high and eighteen miles away). To the right (south) of Isabel in the distance you may see the Pacheco Peaks, Mariposa and Santa Aña mountains. Due south of us is Mt. Toro (fifty-five miles distant and 3,500 feet high) and a very rugged mountain—Murphy's Peak—six miles off. On the horizon near this you may see the waters of Monterey Bay. A little further to the west and we come again to the now familiar landmark of Loma Prieta. Between this and Tamalpais you may catch a glimpse of the sea horizon, eighty-seven miles distant. We have oriented ourselves and begun to know our surroundings. At sunrise the summits of the Sierras (130 miles off) can be plainly seen, and there are times when Lassen's Butte (175 miles) is visible.

Leaving the splendid panorama of the hills, we look at the buildings immediately around us. We are on the roof of the observatory proper. At the north end of it is the twenty-five-foot dome, which



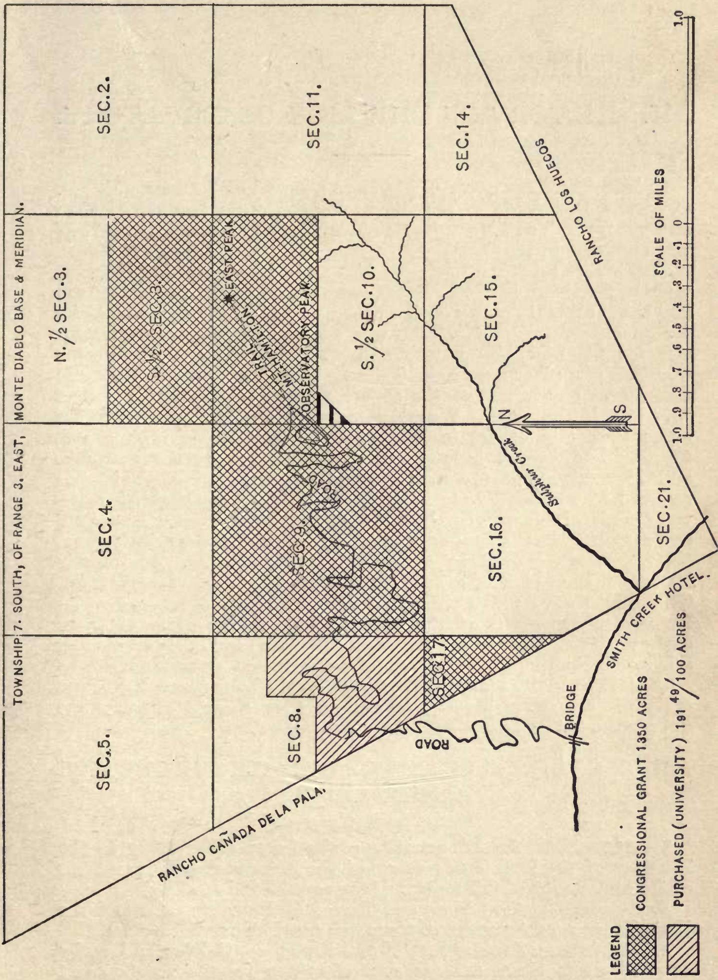
THE OBSERVATORY BUILDING AND THE 75 FOOT DOME
From the West facing San José, (Photographed by Mathews.)



THE OBSERVATORY BUILDING. From the West, facing San José. (Photographed by Mathews.)

covers a telescope of twelve inches aperture. Directly opposite to it, at the south end, is the great seventy-five-foot dome. Towards the northeast are the houses which cover the transit instrument and the meridian-circle; beyond them is the brick dwelling-house of the astronomers. These small buildings nearer to us are for some of the minor instruments. That little dome covers a very perfect six-inch equatorial.

But it is time to descend and go through the various rooms of the observatory building. There, with the explanations of our guide, we may gain some idea of what all these constructions are for; why there are so many of them; and finally, with what object these changes have been made on the summits of the silent hills. Recollect that it was only a few years ago that a wilderness was here. Why has it been so transformed? Was it worth while? What may be expected from all this? There should be satisfying answers to all these questions.


TOWNSHIP 7. SOUTH, OF RANGE 3. EAST, MONTE DIABLO BASE & MERIDIAN.
SEC.2.
SEC.11.
SEC.14.
N. 1/2 SEC.3.
S. 1/2 SEC.3.
EAST PEAK
MT. HAMILTON
TRAIL
OBSERVATORY PEAK
S. 1/2 SEC.10.
SEC.15.
SEC.4.
SEC.9.
ROAD
SEC.16.
SEC.21.
SEC.5.
SEC.8.
SEC.17
RANCHO LOS HUECOS
RANCHO CAÑADA DE LA PALA.
Sulphur Creek
SMITH CREEK HOTEL.
BRIDGE
ROAD
N
S
SCALE OF MILES
0 .1 .2 .3 .4 .5 .6 .7 .8 .9 1.0
LEGEND
CONGRESSIONAL GRANT 1350 ACRES
PURCHASED (UNIVERSITY) 191 49/100 ACRES

IV. HISTORY OF THE LICK OBSERVATORY.

In 1874 MR. LICK gave $700,000 to a Board of Trustees (MR. D. O. MILLS, President) to provide a telescope "more powerful than any yet made"; and "a suitable observatory connected therewith" was specified in the deed.

Just before this time Professor YOUNG had been making observations at Sherman, in the Rocky Mountains, and Professor DAVIDSON had made several reports on the fitness of the high Sierras as a site for an observatory. Mr. LICK was advised to choose a mountain site for his new observatory and was seriously considering the selection of a place near Lake Tahoe. This site was subsequently abandoned on account of the severe winters, etc. In the fall of 1874 Mr. MILLS came to Washington to consult Professor NEWCOMB and myself and others in Washington. The whole matter was thoroughly discussed between us and a project for the buildings and instruments of the new observatory was made. This was reduced to writing by me in October, 1874, and rough sketches were made of the principal buildings, etc., by Professor NEWCOMB and myself. As it was then a question whether "the most powerful telescope" should be a reflector or a refractor, Dr. HENRY DRAPER'S counsel was asked for and freely given. Sir HOWARD GRUBB also gave much time to projects for the observatory. A frame of photographs at the observatory exhibits some of these early projects. One of Sir HOWARD GRUBB'S plans advises placing a large telescope at the bottom of a great well excavated in the rock and closed by a sliding lid at the level of the summit. These early projects have great interest, as they show through what changed conditions the observatory has passed.

ACT OF CONGRESS GRANTING THE SITE FOR THE LICK OBSERVATORY.

Forty-fourth Congress.

CHAPTER 120. An Act granting a site for an observatory to the Trustees of the Lick Observatory of the Astronomical Department of the University of California. (Approved June 7, 1876.)

Be it enacted by the Senate and House of Representatives of the United States of America, in Congress assembled:

That, whereas, JAMES LICK, of San Francisco, California, has, by deed of trust, given a large sum of money for the erection and equipment of an observatory, dedicating the same to the Astronomical Department of the University of California, for scientific and

educational purposes, and has selected Mt. Hamilton, in the County of Santa Clara, the State aforesaid, as the site for said observatory, and which is situate on the public lands of the United States, in township seven south, and range three east, Mt. Diablo meridian, the following described land in said township is hereby reserved from sale or disposal under the general laws of the United States, to wit:

Section nine, the north half of section ten, the south half of section three, and the fractional section seventeen.

SEC. 2. That so much of said land as is not already granted or disposed of by the United States, to wit, section nine, the north half of section ten, the south half of section three. and fractional section seventeen, be, and the same is hereby granted to the Trustees of the Lick Observatory of the Astronomical Department of the University of California, with authority and in trust to convey the same to the Regents of the University of California, and their successors, in trust for the use and benefit of the Astronomical Department of the University of California; *provided*, that if the land herein granted shall be used for any other purpose than the site of said observatory, and the necessary purposes in connection therewith, the same shall revert to the United States.

In 1875 Professor NEWCOMB was asked to go to Europe to see where glass discs of a large size could be had. It was strongly urged upon Mr. MILLS that Mr. BURNHAM should test the excellence of the various sites under consideration by actually making astronomical observations at each of them before a final selection was made. This suggestion was not carried out till 1879, however. When Mr. MILLS returned to California, he found that Mr. LICK was not satisfied with the policy of his Trustees, and after a time the Board resigned and a second Board was appointed. Mr. LICK was equally dissatisfied with the policy of the second Board and finally a third set of Trustees was selected in 1876, which has acted until the present time. On Mr. LICK's death, in 1876, many distressing legal complications arose, and it was not until 1879 that they were finally disposed of, and work on the observatory was begun.

In 1876 I met Capt. FLOYD, the President of the Lick Trustees, in London, and together we visited various observatories and astronomers. Capt. FLOYD also spent some months on the continent on the same business. In the mean time Mr. LICK had agreed to build his observatory at Mt. Hamilton in Santa Clara county, on condition that the county should build a road to the summit. This road, 26 miles long, costing $78,000, was built in 1876. The selection of Mt. Hamilton, rather than Mt. Diablo, Loma Prieta, St. Helena, or a mountain further south was made by Mr. LICK on the report of Mr. FRASER, who has been the efficient superintendent of construction of the Lick Observatory from 1876 to November, 1887.

In 1879 Mr. BURNHAM was invited by the Lick Trustees to bring his six-inch telescope to Mt. Hamilton and to observe double stars there, so that he could test the quality of the vision and compare it with that of Chicago, Hanover (N. H.) and Washington. Mr. BURNHAM spent August, September and part of October on the mountain, in camp. In a capital report to the Lick Trustees (1880) he gave the results of his work. It was found that the nights of summer and autumn, say April to October or November, were excellent both as to clearness of vision and as to steadiness. The daylight hours are less satisfactory. Mr. KEELER has lately shown that the vision in winter time is not specially better than that at lower elevations. The secret of the steady seeing at Mt. Hamilton lies in the coast fogs. These roll in from the sea every afternoon in summer, rising 1,500 to 2,000 feet. They cover the hot valley and keep the radiation from it shut in. There are no fogs in the daytime and few inthe winter. A portion of Mr. BURNHAM's interesting and valuable report is reprinted here.

REPORT OF MR. S. W. BURNHAM (1879).

Situation of Mt. Hamilton: "The City of San José, the nearest point of railroad communication from Mt. Hamilton, is 50 miles south of San Francisco. Mt. Hamilton, by the highway, is 26 miles from San José, nearly east, and is reached by a good road, constructed by the County of Santa Clara. In order to keep the grade within the limit of six feet in one hundred, the last portion of the road is carried up the ridges of the mountain by a circuitous route. The distance between the Observatory and San José, in an air line, is only 13 miles.

The approximate geographical position of the Observatory peak is:

Longitude.................2h. 58m. 22.2s. (Washington.)
Latitude..................................37° 20′ 24.6″.

The elevation of this point is 4,209 feet above the level of the sea. The north peak, which is about four-fifths of a mile distant is 171 feet higher. The ridge between is lower, along which is a good trail connecting the two peaks. The sides of the mountain, in most directions are very steep, and form an acute angle at the summit. The view from the peak is unobstructed in every direction, there being no higher ground within a radius of 100 miles.

At sunset the Pacific Ocean is seen over the summit of the Coast Range at various points; and occasionally a snow-covered mountain was seen in a northerly direction, supposed to be Lassen Butte, the distance of which is about 175 miles. The great range of the Sierra Nevada, about 130 miles distant, came out sharp and distinct at sunrise.

Weather: The kind of weather for astronomical purposes during the whole period of 60 days from August 17 to October 16, 1879, inclusive, was briefly as follows:

First-class nights	42
Medium	7
Cloudy and foggy	11

By first class seeing I mean such a night as will allow of the use of the highest powers to advantage, giving sharp, well-defined images, and when the closest and most difficult double stars within the grasp of the instrument can be satisfactorily measured. In ordinary situations, the clear nights would be divisible into at least four classes, which might be described as *very good*, *good or medium*, *poor*, and *very poor*. While there might be some difference in the nights on Mt. Hamilton I have described as *first class*, the difference seemed not to be sufficient to place any of them in a lower grade. The conditions were generally very permanent for the entire night, and this is not often the case in eastern localities where I have used a telescope. It may grow better, and may get worse, but rarely continues the same the whole night. On many nights, at Mt. Hamilton, I remained at the instrument until daylight, and so had abundant opportunities to observe this important fact.

The average daily maximum temperature in the shade, for the first five weeks, was 88° and the minimum 64°. The thermometer at 9 P. M. would ordinarily be 12° or 15° lower than at 3 P. M.

In connection with the dryness of the air the heat did not seem to be excessive, and it was seldom uncomfortably warm in the shade. The extreme range of the barometer during this time was between 25.30 and 25.45 inches from August 17 to October 16. During the last two weeks a much lower temperature was reached, on one occasion the minimum thermometer indicating 30°.

Observations: Many celestial objects in all the different classes were examined with the telescope at different times, and if they are not all referred to here, it is for the reason that the observations would furnish no satisfactory evidence of what could be done at this place with a 6-inch object glass. The appearance presented by the moon, planets, nebulæ, etc., under high powers in a steady air, may be satisfactory to the observer who is familiar with them under other circumstances, but such observations would have no value in aiding others to form an opinion of how much could really be seen. There is but one class of objects by which the atmospheric conditions of a locality, or the perfection of an object glass or mirror, can be thoroughly tested and a record made. This is by discovering, observing, and measuring difficult double stars, and particularly those which are less than the theoretical separating power of the instrument, and those which are both close and unequal. It is well known what a first class refractor of any given

aperture will do in dealing with test objects. The catalogues furnish a great variety of stars suitable for this purpose, many of which I have examined and measured, as the accompanying observations show. The value of this work, as bearing upon the question at issue, will be best appreciated by those who have had practical experience in this class of astronomical work.

I prepared a series of cardboard discs, with apertures from one inch up to the full aperture of the object glass, and observed a great many familiar objects, cutting down the light until the small star was just distinctly visible. Most of these stars have been used for a similar purpose elsewhere, and are well known to astronomers as well as to amateurs having the smallest portable instruments. The advantage of these tests is, that the observations can be repeated by any one, at any place, with a large or small telescope. Some of these observations are remarkable, considering the difficulty of the objects, with much larger apertures, in other localities. I am confident that *Mu Herculis, Alpha Capricorni*, etc,, have never been seen before with so small an object glass. They have always been beyond the reach of this instrument in Chicago.

NEW DOUBLE STARS.

It is evident that the most satisfactory and conclusive proof of the quality and kind of seeing would be furnished by the discovery of new stars. Whatever advantage might be supposed to exist in the observation of familiar objects, from knowing where to look for a difficult star, would certainly be wanting in discovering and fixing the position and distance of a star, never before seen. Partly for this reason, I gave some time to an examination of the heavens for the detection of new double-star systems, and particularly to that portion lying more than 30° or 35° south of the celestial equator. Most of the time was spent in the southern zones, as that to me was a new heavens, and the most promising field for such research. The result is very gratifying, and furnishes some of the most interesting discoveries, and among the prominent and well known stars, and at the same time shows the wonderful purity and steadiness of the air almost down to the very horizon. It might be supposed there would be little left to do, at least for a small instrument, among the naked-eye stars, even in the southern hemisphere, and particularly when at Mt. Hamilton these stars had to be observed within a few degrees of the horizon. Sir JOHN HERSCHEL had traveled over this whole field at the Cape of Good Hope, where these stars are nearly overhead, with his "twenty-foot reflector," giving nearly ten times the light of the six-inch telescope I was using on Mt. Hamilton; and one not familiar with what large reflecting telescopes have done, and have failed to do, might suppose that but little would be left for discovery, at least among the large stars. So far from this being the case, the fact is that almost nothing has been done in this great

department of discovery and work, by any observer in the southern hemisphere. It is a work which requires too perfect an instrument to be successfully undertaken by any of the large reflecting telescopes heretofore used. The catalogues of HERSCHEL contain very few first class objects, the great proportion being very wide, insignificant, and easy pairs, suitable as tests only for the smallest refractors. Fortunately, a zone of 15° or 20°, too far south for any other American or European observatory, can be observed at Mt. Hamilton, and it is to be hoped that the work now commenced will not be neglected when the new observatory is established. In the mean time these stars will remain for the most part unobserved, since but very few of them can be sufficiently well seen at any of the northern observatories.

The small refractor on Mt. Hamilton has divided again the principal components of several wide pairs previously catalogued by HERSCHEL, STRUVE and SOUTH, transforming a wide pair into a close triple.

In regard to the northern new stars, it is sufficient to say that some of them are excessively difficult, and make excellent tests for the condition of the air. Good weather and good definition are as necessary in observing such stars with a large instrument as a small one. After my return to Chicago I examined one of the new stars I had discovered at Mt. Hamilton with the six-inch telescope by means of the 18½-inch refractor of the Dearborn Observatory, and the first night nothing could be done with it. The large star did not appear to be double at all. Subsequently, when the air was better, it was well seen and measured carefully on two occasions.

Besides the new double stars discovered, a great many known double stars were picked up independently, both north and south. In fact, most of the closer stars in the southern zone, previously observed by Herschel and others down to—45° decl., were found on different occasions.

These stars will show, better than anything else can, what may be done at Mt. Hamilton. Remembering that they were discovered with what, in these days of great refractors, would be considered as a very inferior instrument in point of size, we may form some conception of what might be done with an instrument of the power of that at the Naval Observatory at Washington (26 inches), having a light power about nineteen times as great, or with the Pulkowa glass (30 inches) of twenty-five times the power.

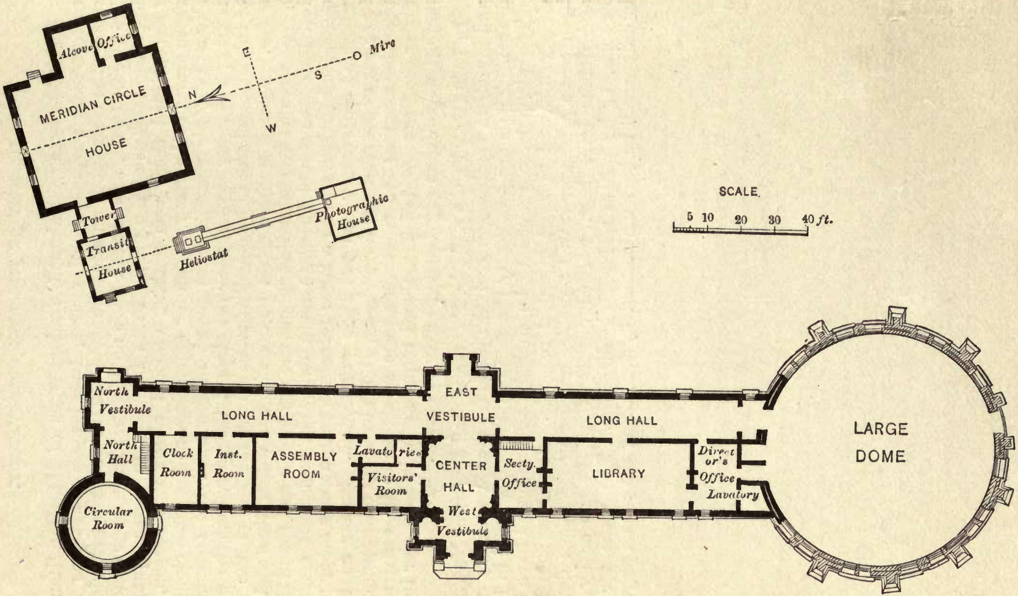
Daylight Observations: A great many objects were examined by daylight, but the air, during the greater part of the day at least, appears to be no steadier than would ordinarily be found elsewhere. The heat of the sun during the warmer part of the season produces a disturbance of the air which disappears very soon after sunset. The sun, planets and double stars were frequently looked at and some measures of double stars made. Double stars like *Epsilon*

Bootis and *Epsilon Lyræ* could be very easily seen. The fifth and sixth stars of the trapezium of *Orion* were beautifully seen in broad daylight just before sunrise. The sixth star was measured on this occasion without artificial illumination, and continued to remain visible as long as it was looked at, which was up to within seven minutes of the actual appearance of the sun above the horizon. *Venus* was readily seen with the naked eye at any hour of the day, and easily found without an instrument to indicate the place.

Conclusions: So far as one may judge from the time during which these observations were made, there can be no doubt that Mt. Hamilton offers advantages superior to those found at any point where a permanent observatory has been established. The remarkable steadiness of the air, and the continued succession of nights of almost perfect definition, are conditions not to be hoped for in any place with which I am acquainted, and, judging from the published reports of the various observatories, are not to be met with elsewhere. The low altitude at which observations can be made is a matter of no small importance, particularly in connection with the portion of the southern sky not ordinarily accessible to observatories in the northern hemisphere. The ease with which difficult objects can be seen almost down to the horizon will be apparent from the southern declination of many of the new double stars. Close pairs can be observed at least down to 43 degrees south declination. The permanent steadiness of the air during the whole night will greatly increase the amount of telescopic work over what could ordinarily be done in good nights in most places. An examination of my observations at Chicago during the summer of the present year shows that the good seeing very rarely continued the whole night, even when it remained clear. In many instances the conditions favorable for the observation of the most difficult objects would only last an hour or two, sometimes occurring in the first part of the night and sometimes not commencing until after midnight. On Mt. Hamilton there is but little variation of any kind during the dry season. Each day was very much like every other day, and as already shown, the same statement would apply equally well to the nights. Apparently there is but little to be feared from the ocean fogs, as they seldom reach this elevation. Nearly every night, commencing at or soon after sunset, this fog comes in from the Pacific at the Golden Gate on the north and the bay of Monterey on the south, and covers the whole valley between the base of Mt. Hamilton and the Coast Range with a dense mass of vapor, resembling, when seen from above, a great white sea, the tops of the lower hills standing up through it like islands. Ordinarily it is perhaps 2,000 feet lower than the summit of Mt. Hamilton. It does not appear to have any effect on the seeing so long as it is below the summit.

What has been said about the advantages of Mt. Hamilton for astronomical purposes is, of course, based upon what was seen during the time spent on the mountain. This was my first visit to the Pacific Coast, and hence I have no personal knowledge concerning other seasons of the year. From inquiries in various quarters I am satisfied there was nothing unusual about this season, and there seems to be every reason for supposing, as the same cloudless sky and dry air prevails from about March until the commencement of the rainy season, near the close of the year, that the whole of this interval would be equally favorable for the use of the telescope. Even if nothing could be done in the winter time and the nights were as favorable throughout the dry season as I found them, Mt. Hamilton would be much more desirable, and more could be accomplished there with a large telescope than at any other place where an observatory has yet been established. So far as there have been opportunities for judging, it is obviously an appropriate place for erecting and maintaining the telescope to be constructed under the LICK Deed of Trust, and required to be 'superior to and more powerful than any telescope ever yet made.'"

In 1879 Capt. FLOYD and Mr. FRASER visited Professor NEWCOMB and myself in Washington and the plans for the Observatory were drawn. These are practically the same as those discussed in 1874. The plans have proved to be entirely adequate and have been closely followed in most essential respects. Improvements have been made wherever it was possible, and many ingenious devices and details have been worked out by Capt. FLOYD or by Mr. FRASER, or by others under their direction. The plans for the buildings will be best understood by consulting the cut on page 32.



GROUND PLAN OF THE LICK OBSERVATORY

V. DESCRIPTION OF THE BUILDINGS.

At the south end of the observatory is the seventy-five-foot dome. At the north end is the twenty-five-foot dome. They are connected by a hall, 191 feet in length. On the west is a series of study and work rooms. For the next twenty years there will be space in these rooms and in the hall for all the work of the observatory. When it is necessary a second row of rooms can be built on the east side of the hall. Any possible expansion of the Observatory can be provided for by such additional rooms, and by separate detached observing rooms in the immediate vicinity. The visitor should notice the fine set of astronomical drawings (by M. TROUVELOT, of Paris) which hang along this hall. They have been kindly presented to the Observatory by the Hon. JOHN R. JARBOE, of San Francisco, and serve to give a very good general idea of the celestial objects depicted.

The building is of brick, painted. It has a slate roof. Tin was found to be better and has been used for the other buildings. Although the building is one story (with a shallow air space beneath), there is a great deal of floor room on the principal floor and in the low attic. The roof is also utilized by platforms and galleries.

THE DOME FOR THE THIRTY-SIX-INCH REFRACTOR.

The computations for the strength of the arches and of the walls of this dome were made by Prof. BULL, of Madison, Wis., in 1885, and forwarded to the Lick Trustees. The contract for the dome proper was awarded to the Union Iron Works of San Francisco, in 1886, and the dome was finished in place in October, 1887. The details of plans were thoroughly worked out by Mr. DICKIE, of the Union Iron Works, and by Mr. FRASER. No adequate notion of the design can be had without wood cuts which I have no way of producing here. It may suffice to say that the outside diameter is 75 feet 4 inches; the inside 71 feet. The dome stands on a smooth cylindric wall of brick 3 feet 2 inches thick at base, 2 feet 3 inches at the top. This wall has few openings in it.

The original design of the brick cylinder, drawn by Prof. BULL from my sketches, is indicated on the plan of the buildings accompanying this. It provided for thorough ventilation and for rapid cooling off of the large masses of brick. This is a very important point and it is not yet certain that it has been secured by the modification actually adopted.

The dome itself is admirably constructed by the makers. The moving parts weigh 199,000 pounds, and can be set in motion by a pull of less than 200 pounds. That is, one pound can move 1,000. The usual motive power is obtained from a water engine which will rotate the dome 360° in less than nine minutes. There are several novel features in the construction; perhaps the most important is the system of expansion bedplates for the track. The diameter of the dome changes one-half an inch in the extremes of temperature, and the track is given a smooth and oiled surface to slide upon (in and out).

The guide rollers are placed on the outside of this dome instead of on the inside, as is usual. Most of the bearings of axles in the dome are anti-friction (bicycle ball) bearings.

The shutters weigh	16,000 lbs.
Total weight of cupola	174,000 "
" " " live ring	25,000 "
" " " moving parts	199,000 "
" " " metal in dome	269,000 "
" " " elevating floor	50,000 "
Total number of rivets and bolts	250,000 "

The observing slit is nine and one-half feet wide.

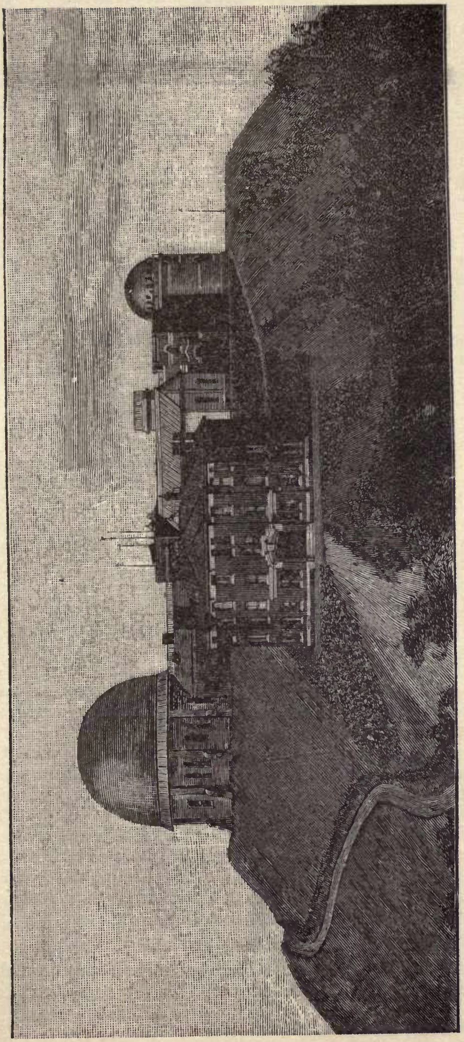
THE ELEVATING FLOOR.

A very ingenious plan was proposed by Sir HOWARD GRUBB to the Lick Trustees for placing the observer at a proper height (any where from zero to thirty-seven feet above the floor). The idea was to have a portion of the floor move bodily up and down, like an elevator. This plan was adopted by the Lick Trustees and the floor has been built by the Union Iron Works. My recommendation to the Lick Trustees was that the floor should move at the rate of four feet per minute. The motive power originally provided (a three cylinder 8 × 6 water engine) required ten times as long. It is probable that this speed can be materially increased by changes in the hydraulic arrangements, which are now being made by the Lick Trustees, and if not the motive power can be replaced by steam or electricity, should the present speed be found materially too slow.

The moving floor is 61½ feet in diameter and weighs 50,000 pounds, which is nearly all counterpoised. By suitable changes it is certain that the ingenious plan of Sir HOWARD GRUBB can be made available and convenient. The speed actually required can hardly be definitely fixed until a series of observations has been made.

THE DOME FOR THE TWELVE-INCH EQUATORIAL.

This dome is a hemisphere 25 feet 6 inches in diameter, made of thin plates of nickel-plated copper secured to a light frame-work of



VIEW FROM THE NORTH-EAST—(The large Dome is copied from a design, not from Nature.)

wood. The slit for observation is 3 feet wide and extends beyond the zenith. The shutter is part of a cylinder tangent to the sphere of the dome, and was made by WARNER & SWASEY in 1887. The mechanism for revolving the dome is novel, simple and efficent, and is the invention of Capt. FLOYD and Mr. FRASER. An endless rope passes around the outside of the dome just above the base-plate, over guiding pulleys and down around a groove in a two-foot wheel placed in a recess in the wall of the room below. This wheel is rotated by a crank geared in the proportion of 3 : 1, and the friction of the rope on the outside is sufficient to turn the dome. To give the dome a complete revolution requires forty-one turns of the crank, and it can easily be effected in less than two minutes. The approximate weight of the dome is eight tons.

MERIDIAN CIRCLE HOUSE.

The Meridian Circle house, completed in 1884, from drawings made from my plans by Professor COMSTOCK, is 43 × 38 feet with a wing 27 × 11 feet on the east. The walls are double throughout. The outer frame carries a louvre work of galvanized iron, which completely prevents the sun from striking any part of the building proper. The inner walls are of California redwood, and between these and the outer walls is an air-space twenty-four inches wide, which extends completely around the building. The ceiling is also of redwood. It is sixteen feet above the floor, flat in the centre of the room and arched over to connect with the side walls. A very large air-space above the ceiling communicates with the room itself and with the air-spaces of the walls. On the west the rooms open into a ventilating tower two stories in height, which also adjoins and is connected with the house for the meridian transit instrument, which lies still further to the west. The design of this construction is to keep the temperature of the two houses and of their air-spaces precisely the same as that of the external air, and it is probable that this object has been practically attained. The upper room of the ventilating tower ought to furnish an admirable exposure for meteorological instruments.

The wing on the east side projects eleven feet from the main building, and contains an office room for the observer and an alcove to receive the glass house which protects the instrument when not in use. The slit for observation is 3 feet 4 inches wide. At the north and south it is closed by double shutters 20 feet high, and overhead by four shutters, each 25 feet long and 2 feet wide, hinged at the side of the slit and opening outward. These shutters were devised by Mr. FRASER, are perfectly weathertight and very convenient in use. They are the best that I have seen.

THE TRANSIT HOUSE.

The Transit house adjoins the Meridian Circle house on the west. It is built of iron with a wooden lining, after the manner of the

Meridian Circle house, but the air-spaces are smaller. The room measures 18 feet in an east and west and 14 feet in a north and south direction. The roof is arched, and the central opening is covered by a curved shutter, which is controlled by levers inside on the plan of Sir HOWARD GRUBB. Sliding shutters on the north and south allow the instrument to point to the northern horizon and to the object glass of the photoheliograph which serves as a south collimating lens.

PHOTOGRAPHIC LABORATORY.

This is in a small wooden house with brick foundation, 16 feet in an east and west and 12 feet in a north and south direction, situated 60 feet south of the Transit house. The tube of the photoheliograph telescope enters the building 2½ feet to the east of the center. The laboratory is 13 × 12 feet. It is lighted by two windows, one of which is of red glass, in the west end. Both are provided with shutters. On the north is the brick pier which supports the plate-holder of the photoheliograph. A room on the second floor of the main building next to the seventy-five-foot dome is also fitted for photography.

THE DWELLING-HOUSES.

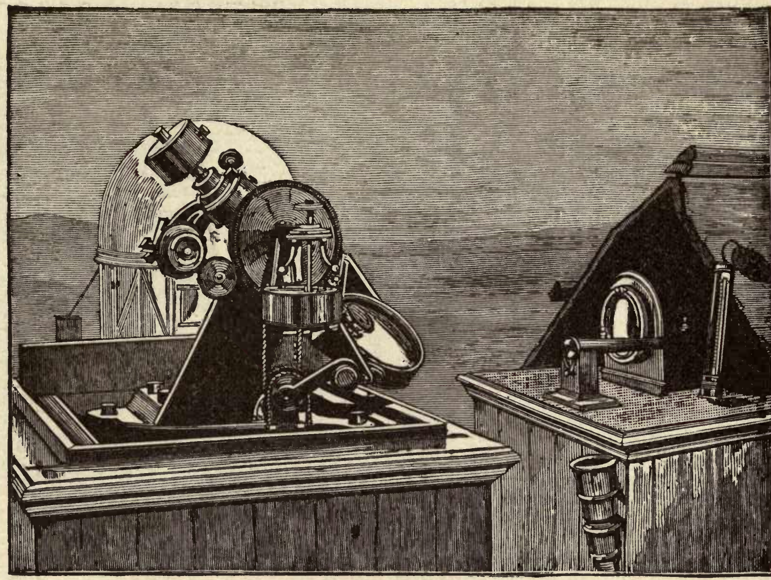
The astronomers' dwelling consists of a brick building 63 × 60 feet and three stories high, situated on a level bench of ground excavated for the purpose to the eastward of the observatory and about 22 feet below the summit. A long flight of steps leads up from the plateau on which the cottages are situated to the principal entrance.

The building contains two distinct and precisely similar dwellings, which, however, may be made to communicate when desirable by doors in the partitions. The floors of the third story and the summit plateau are on the same level, and are connected by a bridge, which gives easy access to the observatory.

SHOPS, BARNS, AND COTTAGES FOR ASTRONOMERS AND WORKMEN.

The cottages are situated on the saddle of the mountain connecting the Observatory peak and Mt. Tycho, where a level place was cleared for the purpose. At the foot of the flight of steps leading up to the astronomers' residence is a large double cottage containing eleven rooms, formerly occupied by the superintendent. One large cottage and two smaller ones are but a short distance off, with sheds for poultry, etc. A little further along is a large barn with stables, and north of this a long, low house which has been used by workmen.

On the observatory plateau, east of the main building is a low brick building containing a carpenter shop and separate rooms for oil, paints, a blacksmith's forge, etc.

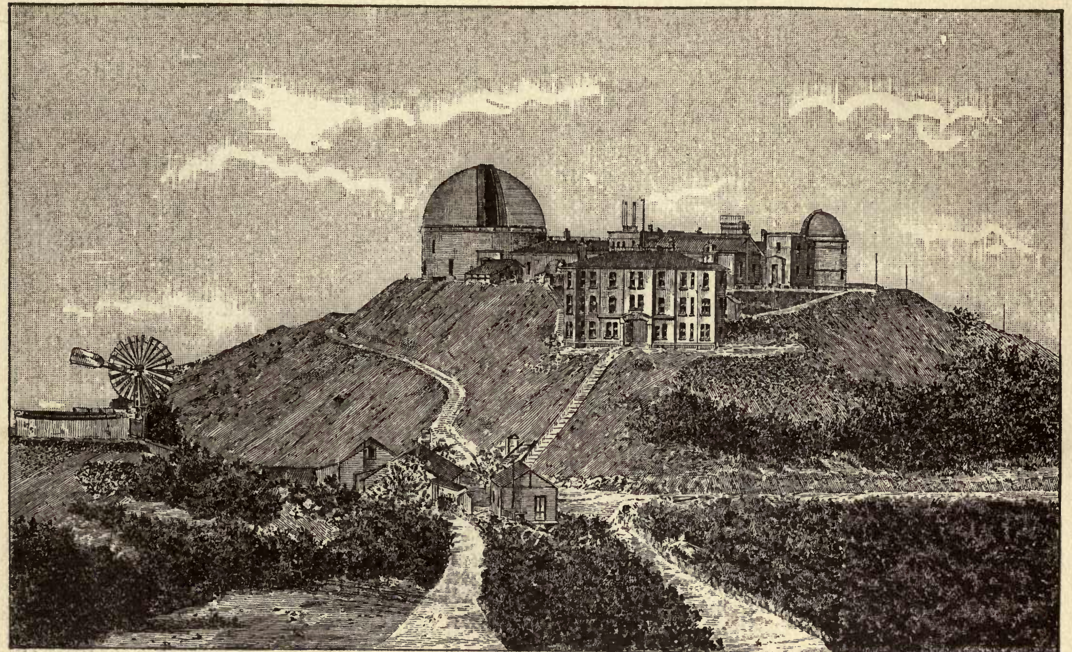


PHOTOHELIOGRAPH OBJECTIVE WITH HELIOSTAT
Made by Alvan Clark & Sons
The Dome for the six-inch Equatorial is shown in the back ground

THE WATER-SUPPLY.

The principal source of water is a spring, (*Aquarius*), situated on the southern slope of Mt. Galileo, about ¾ of a mile from the observatory. A reservoir holding 27,000 gallons collects the water, which is then forced by a steam pump through a 2-inch pipe ¾ mile long into the reservoir on Mt. Kepler, 388 feet above the spring. Steam is supplied to the pump from a 20 horse-power boiler, for the transportation of which a road had to be cut from the observatory in the side of the mountain. The reservoir on Kepler is built of brick and cement, and has a capacity of 85,000 gallons. Pipes lead from it to supply the buildings of the workmen, the astronomers' dwelling and the observatory. The head of water at the level of the plateau is 48 feet. A 1½-inch pipe also leads to a reservoir on Huyghens' Peak, an elevation near the workmen's quarters. This reservoir is built in the same manner as the first, and has a capacity of 65,000 gallons. It is below the level of the buildings on the summit, and in the winter and spring is kept full of rainwater collected by their slate roofs. For this purpose a 2-inch pipe was laid deep in the ground before blasting was begun on the mountain. As the carrying capacity of this pipe is not sufficient during very heavy rains, a reservoir 10x6x4 feet, in which the surplus of water can accumulate, is provided under the main building. In the summer or dry season, the reservoir on Huyghens' Peak is filled from the main one on Kepler by means of the 1½-inch pipe above mentioned. In addition to these reservoirs four wooden tanks, two of 5,000 gallons each, one of 2,000 gallons and one of 1,000, collect the rainwater from the roof of the Meridian Circle House.

During the summer of 1886 a third reservoir, to contain about 30,000 gallons, was built on Mt. Copernicus, 171 feet above the observatory floor and 4,000 feet distant. This can be filled either directly by the steam-pump at the springs, or by a windmill-pump erected on the Huyghens' Peak reservoir. The water from this source serves to turn the large dome and to elevate its lifting-floor. It is also an important safeguard against fire. Until this water supply was developed all our water had to be hauled from Smith Creek 2,000 feet below the summit and 7 miles distant.



VIEW OF MT. HAMILTON FROM NORTH-EAST
Astronomer's dwelling in the foreground. (Photographed by Mathews.)

VI. DESCRIPTION OF THE ASTRONOMICAL INSTRUMENTS.

THE THIRTY-SIX-INCH TELESCOPE.

There is no way for the visitor to obtain any adequate idea of the great size and of the mechanical perfection of the large telescope except by seeing it and by verbal explanation. Therefore I simply give below a few of the dry statistics, and leave the visitor to form his own impression from an actual view. It is far more difficult to convey in untechnical language any idea of its *optical* superiority over all other instruments. In section VIII following this, I have given a short sketch of the development of the telescope as a seeing instrument, and in section X some account of its use in Astronomical Photography; these sections may therefore be referred to in this connection. It is very difficult also to obtain any satisfactory picture of this instrument. In short, it is necessary to see the telescope itself to know what it is like.

The visual objective is 36 inches clear aperture and 672 inches focus. One second at the focus is therefore about $\frac{3}{1000}$ of an inch. The image of the sun at the focus is about 6 inches in diameter. The photographic lens is 33 inches in aperture and about 550 inches focus. The photographic image of the sun is therefore $5\frac{1}{10}$ inches in diameter. The history of the objective is as follows: The flint disc was obtained from FEIL, in Paris, in April, 1882. After nineteen failures, the crown was successfully cast in September, 1885. In 1886 a third (photographic) crown disc was purchased also from FEIL, which was cast at the same time with the successful crown disc for the visual objective; it broke in the hands of the Clarks in 1886. In 1887, Mr. ALVAN G. CLARK went to Paris and procured the crown glass from FEIL, which has been worked into a third lens.

The visual objective was completed by the CLARKS and delivered in 1886, so that it has waited for a year for the dome and hydraulic apparatus. Those who are interested in the methods of manufacture of object-glasses will find an excellent popular account in the *Scientific American* for Sept. 24, 1887. The mounting is by WARNER and SWASEY and all the details of its construction have been worked out by them except those of the eye-end, which were drawn by Professor BULL of Madison, from sketches by Professor LANGLEY and myself. The tube is nearly cylindric in shape, with a suitable port for access to the photographic focus. The counterpoising is arranged so that the photographic lens can be put on and taken off

safely and quickly. There are three regular finders, 6, 4 and 3 inches in aperture. In addition to these, the 12-inch equatorial can be quickly attached as a pointer for photographic work should the controlled driving clock not prove satisfactory.

The following mechanical movements are provided:

An observer at the eye-end can

1. Clamp in declination.
2. Give slow motion in declination.
3. Read the declination circle (two verniers).
4. Clamp in right ascension.
5. Stop the clock.
6. Give slow motion in right ascension.
7. Read right ascension circle (one microscope).

An assistant on *either* side of the balcony below the axes can

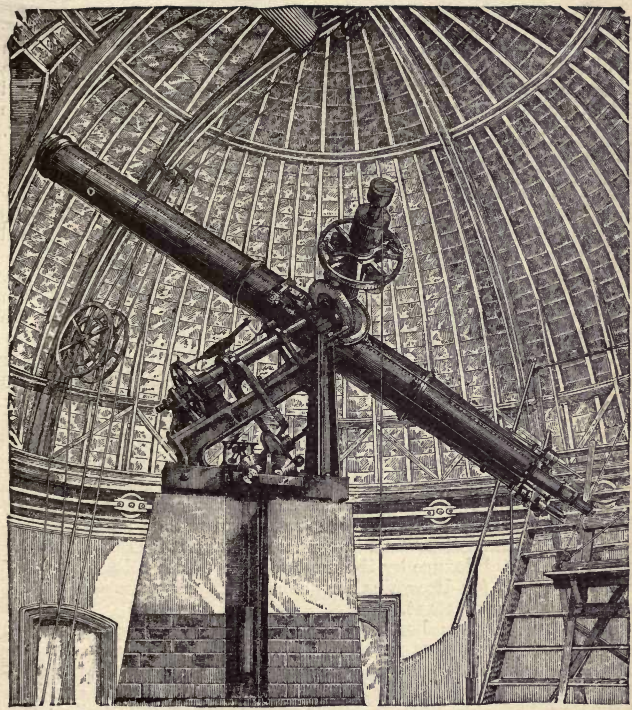
8. Clamp in declination.
9. Give rapid motion in declination.
10. Give slow motion in declination.
11. Give quick motion in right ascension.
12. Give slow motion in right ascension.
13. Clamp in right ascension.
14. Stop or start the driving clock.
15. Read the right ascension circle (two microscopes).
16. Read a dial showing the nearest quarter degree of declination.

The original design of the makers allowed everything which is now done by an assistant on the balcony to be done by a person on the floor. The distance from the base of the iron pier to the center of motion is 37 feet 10 inches exactly, and to the lowest position of the (movable) floor is 35 feet 11 inches, leaving a clearance of 7 feet 10 inches for the eye-piece, or of about 3 feet 7 inches for the star spectroscope. The eye-end is so arranged that the micrometer can be quickly removed, and two steel bars inserted in bearings. These bearings are part of a jacket around the eye-end. This jacket revolves smoothly 360° in position-angle. Spectroscopes, photometers, enlarging cameras, etc., can be readily attached to these bars. In this way this telescope mounting is made entirely convenient for micrometric, photographic or spectroscopic work. It is, in fact, three mountings in one.

TWELVE-INCH REFRACTOR BY ALVAN CLARK & SONS.

The objective and tube of this instrument were originally made by ALVAN CLARK & SONS for DR. HENRY DRAPER, and were mounted in his private observatory at Hastings-on-the-Hudson.

The objective is of the very finest quality. It was disposed of by DR. DRAPER in 1879, in order that he might replace it by the photographic objective of 11 inches aperture, now at Harvard College Observatory. The objective was in the hands of the Messrs. CLARK



INTERIOR OF THE NORTH DOME—THE TWELVE-INCH TELESCOPE

(FROM "THE CENTURY" FOR MAY, 1886)

Objective and Mounting by Alvan Clark & Sons. (Magnifying powers from 100 to 1000 diameters)

until September, 1880, during which time a substantial mounting was fitted to it. It was mounted at the Lick Observatory in October, 1881.

FOUR-INCH COMET-SEEKER BY ALVAN CLARK & SONS.

The objective has an aperture of four inches and a focal length of about thirty-three inches. The rays from the objective fall on a reflecting prism midway in the tube and are bent into a horizontal plane. The observer has only to move his eye in azimuth while the telescope tube is moved in altitude, in order to cover the whole sky.

PHOTOHELIOGRAPH BY ALVAN CLARK & SONS.

The photoheliograph is mounted due south of the Transit house. The transit instrument serves to determine the position of the axis of the photoheliograph; and conversely the photoheliograph is used as a south collimator for the transit.

It is essentially of the same form as those employed in the U. S. Transit of *Venus* expeditions of 1874 and 1882 which have been described (with plates) in the "American Observations of the Transit of *Venus*, 1874, Part I."

It was used by Capt. FLOYD and Professor TODD to observe the transit of *Venus* in 1882. (See the cut previously given in Section V.)

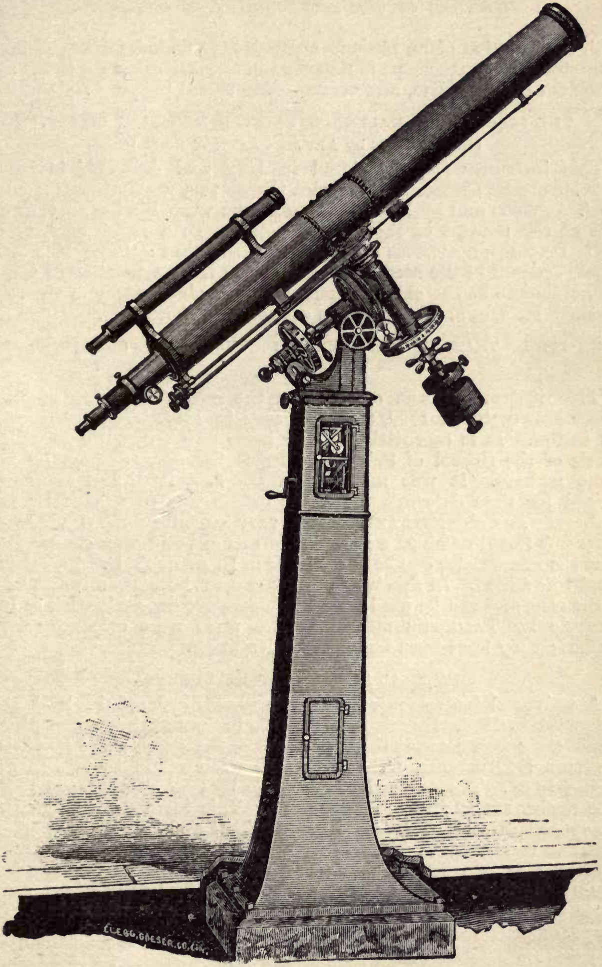
THE SIX-AND-ONE-HALF-INCH EQUATORIAL.

(Objective by A. CLARK & SONS; mounting by WARNER & SWASEY.)

In ordering the Repsold Meridian Circle it was stipulated that the three objectives of equal size which belonged respectively to the circle and to the two collimators, should be made by ALVAN CLARK & SONS. The north collimator is to remain always in position. The south collimator will be used in connection with it for determination of the horizontal flexure by the method of opposite collimators, but can be replaced for determinations of collimation by the south *mire*, about eighty feet distant.

Its objective thus becomes available for other purposes, and Messrs. WARNER & SWASEY have provided a portable mounting for this objective. It is the work of a few minutes to detach the collimator objective in its cell and to adapt it to the tube of the six-inch mounting. The cast iron column of this mounting is hollow and contains the driving clock and weights. It can be taken apart just below the clock for greater convenience in transportation when the instrument is used on eclipse or other astronomical expeditions.

The driving clock has several features of interest. The double conical pendulum is so hung that its period of revolution is very nearly independent of the height of the balls, which always assume the position proper to their velocity of rotation, although the retarding friction increases continually as the balls diverge. The performance of this clock is very satisfactory. A similar clock,



WARNER & SWASEY'S SIX AND ONE-HALF INCH
PORTABLE EQUATORIAL

Objective by ALVAN CLARK & SONS

with the addition of an electric control, is provided for the 36-inch refractor. This telescope is mounted in a small dome south of the Meridian Circle House, and serves many useful purposes.

THE SIX-AND-ONE-HALF-INCH REPSOLD MERIDIAN CIRCLE.
(Object Glass by ALVAN CLARK & SONS.)

This instrument was ordered in 1882 and delivered in 1884. Previous to its dispatch to America it was thoroughly inspected by Prof. AUWERS and by Prof. KRUEGER who were kind enough to do this at the request of the Lick Trustees. In a letter of May 6, 1884, Professors AUWERS and KRUEGER say that: "The Meridian Circle ordered of the Messrs. REPSOLD is in its construction in every way suited to be the chief instrument in an observatory of the first class." Its uses are described in section VII, following.

FOUR-INCH TRANSIT AND ZENITH TELESCOPE, COMBINED, BY FAUTH & CO.

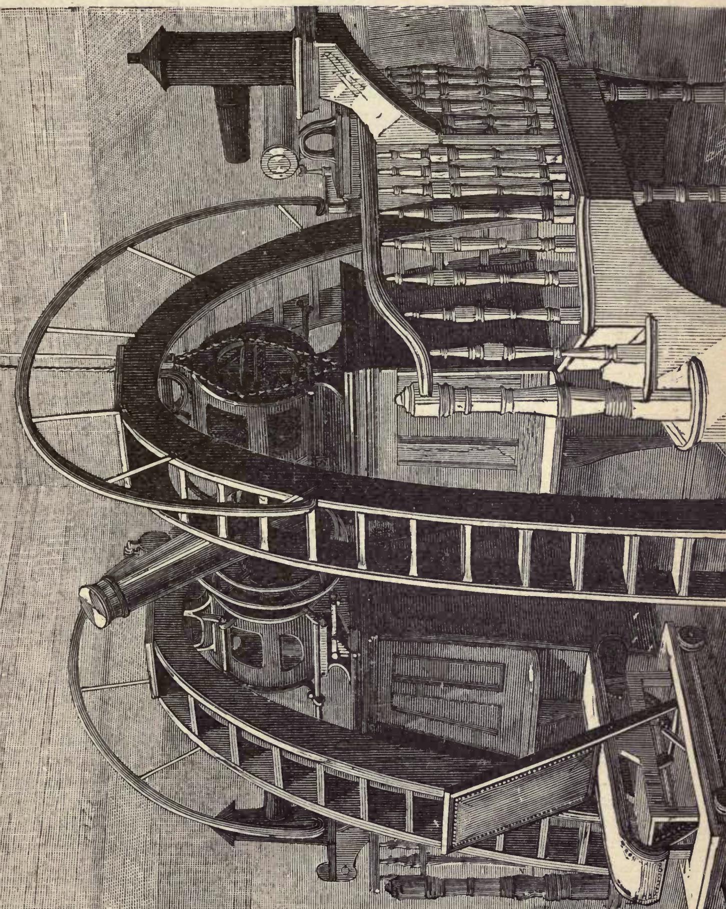
This instrument was ordered, on the recommendation of Professor NEWCOMB, in 1880, and delivered in 1881. The aperture is 4.1 inches. It is essentially of the same pattern as the Meridian Circle of the School of Science at Princeton, New Jersey, by the same makers. It was mounted in October, 1881, and has since served for time determinations. In 1885 it was remodeled by the makers. The objective (which is a very excellent one, by ALVAN CLARK & SONS) received a new cell. The eye-end was changed so that the micrometer can be used either in R. A. or Z. D. A sensitive level was added. In this way the instrument becomes a zenith telescope also, and can be used for an independent determination of the latitude by TALCOTT'S method. The piers were originally iron frames; they have been built solid with brick.

UNIVERSAL INSTRUMENT BY REPSOLD.

A universal instrument, by REPSOLD, was ordered in 1884 and delivered in 1885. Its telescope tube is broken at the middle where a reflecting prism sends the rays through the axis to the eye. Its aperture is 2.15 inches; the horizontal circle reads by two microscopes to 2″. The vertical circle reads by two microscopes to 2″. The circles are 10 inches in diameter. This instrument may serve for special investigations on the refraction; and it is a very perfect geodetic instrument. Together with the six-inch equatorial and a chronometer it constitutes an outfit which can be packed in a few hours and which is very suitable for astronomical expeditions. All these instruments pack readily into boxes of convenient size and shape.

CLOCKS.

There are two dead-beat clocks by HOHWU; two gravity escapement clocks by C. FRODSHAM and DENT respectively; a mean time



clock for time-service work by HOWARD (dead-beat); several chronometers by NEGUS and a thermometric chronometer by C. FRODSHAM. It was originally intended to have a fine clock in each observing room, but a set of controlled clocks (GARDNER'S pattern) has replaced the finer clocks which are now kept in the clock room.

CHRONOGRAPHS.

There is a FAUTH chronograph in the transit room, one in the meridian circle room and a WARNER & SWASEY chronograph in each dome.

THE LIBRARY

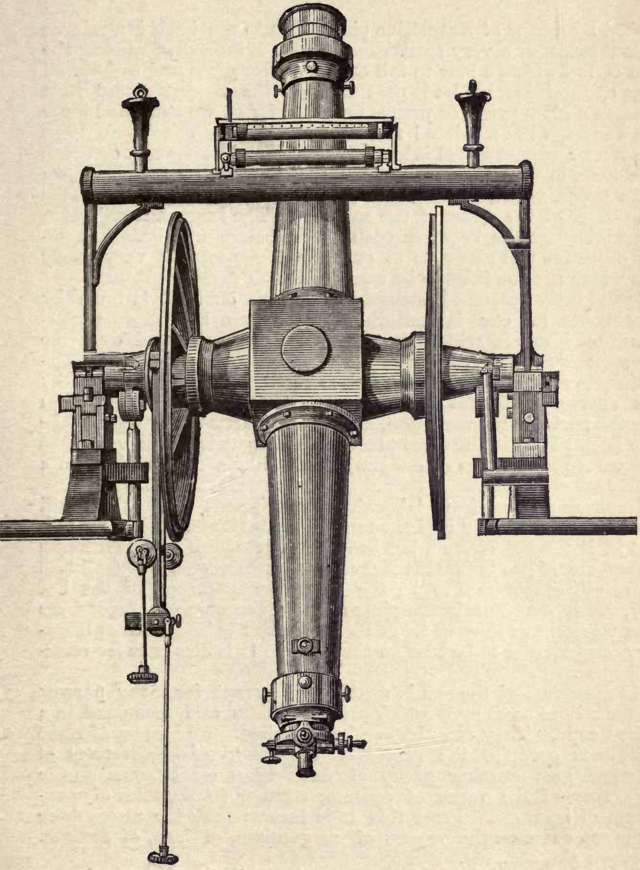
It is entirely proper to count the Library of an observatory as one of its most important astronomical instruments. For the object of all scientific activity is either to learn new things or to know old ones better. To do either it is first necessary to know what has already been learned, and a library gives this essential information. Our special library is not as extensive as it should be, but it contains a selection of the most important books—such as Treatises on Astronomy in general, on special departments, on Mathematics, Meteorology and Physics, Catalogues and Maps of Stars, of Comets, of Nebulæ, etc. It is to be hoped that the Library may be largely increased by gifts in the future.

MINOR INSTRUMENTS.

The Messrs. REPSOLD have furnished the observatory with a leveltrier of refined construction. An engine for measuring photographs, scales, etc., has been made by STACKPOLE & BRO. from designs by Professor HARKNESS. It is similar to the one constructed for the U. S. Transit of Venus Commission. For use in connection with the measuring engine, Professor W. A. ROGERS, of Harvard College Observatory, has provided a standard bar 20½ inches long, containing a half-yard divided into inches and tenths, with two inches at one end minutely subdivided. A delicate spherometer, by FAUTH & Co., is provided, beside resistance-coils, galvanometers, a disc photometer, small spectroscopes, spare prisms, eye-pieces, etc. The most important of the minor instruments are the filar micrometer for the 36-inch, by FAUTH & Co., and the duplex micrometer, by GRUBB. The Lick Observatory possesses a very powerful star spectroscope which has been devised by Mr. KEELER and made by J. A. BRASHEAR, of Pittsburg, as an improved form of the spectroscope employed by Professor C. A. YOUNG of Princeton. Plans for a large solar spectroscope have been worked out by Professor LANGLEY and myself, but the instrument has not been ordered as yet.

SPECTROSCOPES.

One of the most important attachments to the telescope is the spectroscope. The telescope forms the image of a star at its focus and this image can be viewed with an eye-piece; or it can be photo-



FOUR-INCH TRANSIT INSTRUMENT AND ZENITH TELESCOPE, by FAUTH & Co.
For determining Time and Latitude

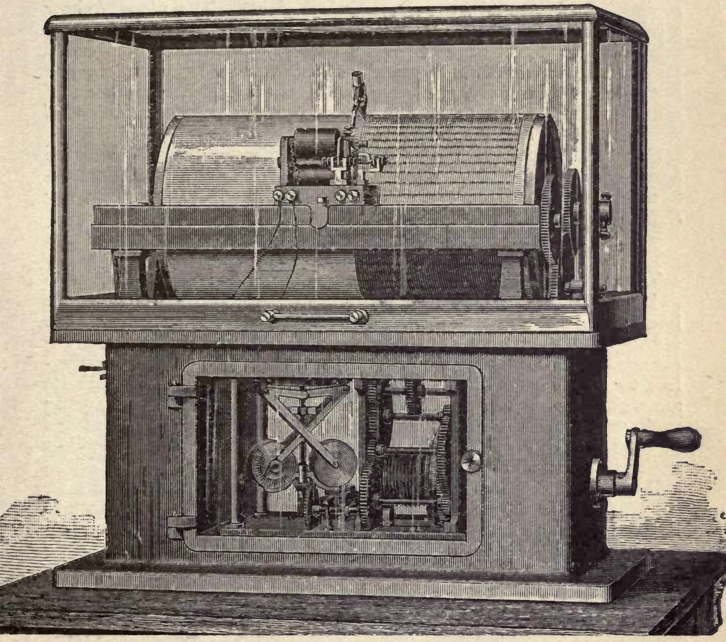
graphed by means of a sensitive plate. The image itself is a minute brilliant point, or a very small disc of light. If instead of causing the beam of light from a star to fall on the object glass and to form an image at the focus, we let it pass through the objective and then fall upon a glass prism or prisms near the focus, we shall no longer have an image but a colored ribbon or *spectrum.* The star's light is no longer concentrated into a brilliant disc but spread out into a spectrum in which the rays of various colors are separately shown in the order, violet, indigo, blue, green, yellow, orange, red. This is the order of the colors of the rainbow. The larger the objective of the telescope the brighter each of the colors will be. The 36-inch objective will allow us to examine the spectra of very many stars which are too faint to be examined with smaller glasses.

A solid body heated so intensely as to give off light is found by experiments (in our laboratories) to produce a *continuous* spectrum; that is one in which the colors are evenly spread over the entire spectrum. A gaseous body so heated, ordinarily gives a discontinuous spectrum; that is a series of bright lines separated by dark spaces. Different gases give more or fewer lines arranged in different parts of the spectrum, but the same gas always gives the same bright lines in the same places. If the gas is under enormous pressure (as in the case of our sun) it acts like a solid and gives a continuous spectrum.

Moreover we find from laboratory experiments that a gas will absorb when relatively cool the same rays that it emits when heated. That is, if the light from a hot body passes through a surrounding atmosphere of gas before it reaches the spectroscope, we shall find the resulting spectrum to be the *continuous* spectrum of the hot body, with *dark lines* in the places where the gaseous atmosphere alone would have showed *bright lines.* All this is known from laboratory experiment to be true on the earth. It is also true for celestial bodies.

The spectrum of the sun is continuous except for many narrow fine dark lines crossing it which are easily seen and measured in a spectroscope. They can also be photographed. One group of these dark lines occupies the places of the group of bright lines of hydrogen gas; another group of dark lines corresponds to the bright lines of the vapor of sodium; another to the lines of magnesium of iron, etc. From this it is known that the atmosphere of the sun contains the vapors of magnesium, of iron, of sodium, hydrogen gas, etc., etc.

The constituent vapors of the atmosphere of other stars or planets can be (and have been) investigated in the same way. First the dark lines actually existing in the spectrum are carefully measured and mapped. Then the coincidences between the position of groups of these dark lines with the groups of bright lines of vaporized metals are noted, and the conclusions drawn.



WARNER & SWASEY CHRONOGRAPH

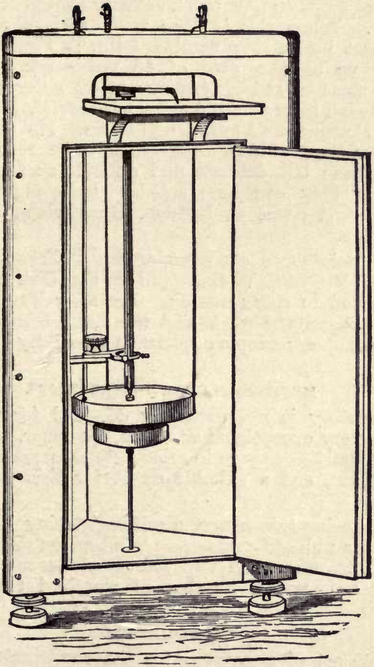
The pen is marking the beats of a clock pendulum (on the right hand side of the revolving barrel in the cut.)

The sun is, in this way, shown to be a gaseous body under enormous pressure, surrounded by a highly complex atmosphere of vaporized metals. Stars are suns. Comets are gaseous bodies composed of carbon, hydrogen, nitrogen and in some cases sodium. The Nebulæ are chiefly gaseous, and their principal constituent gas is nitrogen. The spectrum of the moon is simply an enfeebled solar spectrum (reflected from the moon's surface). The planets show a solar spectrum together with certain peculiar lines, due to the selective absorption of their several atmospheres. The gases sealed up in the cavities of meteoric stones have been examined in our laboratories and these gases show the characteristic spectrum of comets. Here then is a new proof of the intimate connection of meteor-streams and comets.

Some of the principal uses of the spectroscope may be inferred from what has just been said. One of its most important applications, however, will be *to determine the motions of the stars towards or from the earth.*

MOTIONS OF STARS IN THE LINE OF SIGHT.

The observation of a star's *position* — of its longitude and latitude — is really nothing but the determination of the place where the line joining eye and star pierces the celestial sphere. If the star is moving directly towards or from us this position will remain unchanged, and the methods of ordinary astronomy are quite powerless to detect even its existence and still more to determine its amount. But we have in the spectroscope a means of measuring such motions of stars in the line of sight. The principle of the method is simple. Its application is most difficult. Every one has noticed, in travelling upon an express train, the sudden clang of the bell of a train passing in the contrary direction; and how the *note*, the *pitch*, of the sound of this bell rapidly changes from high back to low again. Nothing is more certain than that the bell has but one essential pitch. Why then does it change? The engineer of the passing train hears his own bell giving always the same note, and this note is determined by the length of the sound waves that reach his ear. Suppose them to come at the rate of about 500 per second to him. He is always moving at the same rate as his bell. But to us in the other train the case is different. When the bell is just opposite to us 500 waves reach us in a second; when we are approaching the passing train *more* than 500 come to us (not only the 500 sent out by the bell, but those others which we meet by our velocity); as we leave the passing train, less than 500 waves overtake us per second. Hence the pitch (the number of waves per second) varies. The same thing happens in the case of light. In the spectrum of a star there are certain dark lines whose presence is due to hydrogen in the star's atmosphere. If the star is at rest with respect to the earth, these lines are not displaced in its spectrum; a definite num-



EARTHQUAKE INSTRUMENT BY EWING

During a shock the pen remains steady and writes the horizontal movement of the earth on the (moving) plate of smoked glass.

ber of waves (say A) come to us from the spectrum on both sides of these lines per second. If the star is approaching us *more* waves than A reach us; if the star is receding *fewer* waves reach us. The pitch of the line, so to say, is altered; and the spectroscope can measure this change of pitch and we can calculate how much change of pitch corresponds to how much velocity of approach, or recession, in the star. When this is done with respect to the principal stars the most interesting results follow: *Vega* is found to be approaching us at the rate of 45 miles per second, *Pollux* is approaching us at 40 miles, *Arcturus* at 42 miles etc., etc.; while *Castor* is receding from us at 26 miles per second, *Regulus* is receding at 20 miles, *Procyon* at 44 miles, and so on. No adequate idea of the delicacy of the measures upon which these results depend can be briefly given; but delicate and difficult as they are we have evidence that they can be trusted. Independent observations made at different times at London, Greenwich and Potsdam substantially agree.

The great telescopes of Washington, Pulkowa, Princeton, the University of Virginia, Vienna and of the Lick Observatory are especially suited to this research. Professor YOUNG at Princeton has already begun the work and the LICK telescope is provided with powerful spectroscopic appliances especially designed for the purpose.

METEOROLOGICAL INSTRUMENTS.

The observatory is not primarily destined for a meteorological station. Its very exceptional situation, however, creates a responsibility on its part to engage to some extent in making meteorological observations, and a suitable outfit for this purpose has been obtained.

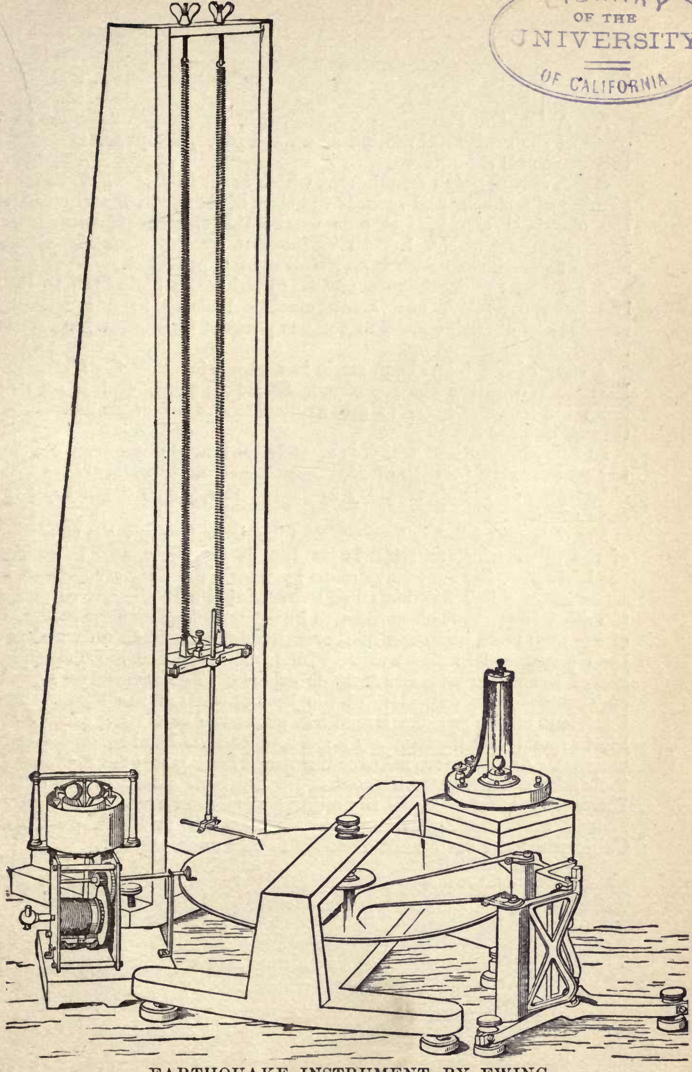
A self-registering rain-gauge, a self-registering barometer (DRAPER'S pattern), and a self-registering wind-gauge (U. S. S. S. pattern) are provided, together with two mercurial barometers (by GREEN and by ROACH), and a number of standard thermometers (by GREEN).

SEISMOMETERS.

A complete set of apparatus for the registration of earthquake movements has been provided by the Cambridge Scientific Instrument Co., from designs by Professor EWING. The separate instruments are as follows:

1. A Horizontal Seismograph, with clock and driving plate. The clock is started by an electric contact at the beginning of the earthquake, and the two rectangular components of the horizontal motion are registered side by side on a moving plate.

2. A Vertical Motion Seismograph, to register the vertical movement of the surface of the earth on the same plate.



EARTHQUAKE INSTRUMENT, BY EWING

The three pens stay still during a shock, while the glass-plate moves with the earth. The right hand pen writes the earth's East and West motion, the next pen, the North and South motion; the left hand pen writes the earth's vertical motion.

3. A Duplex Pendulum Seismograph, to give independent records of the horizontal motion on a fixed plate, the pencil being free to move in all azimuths.

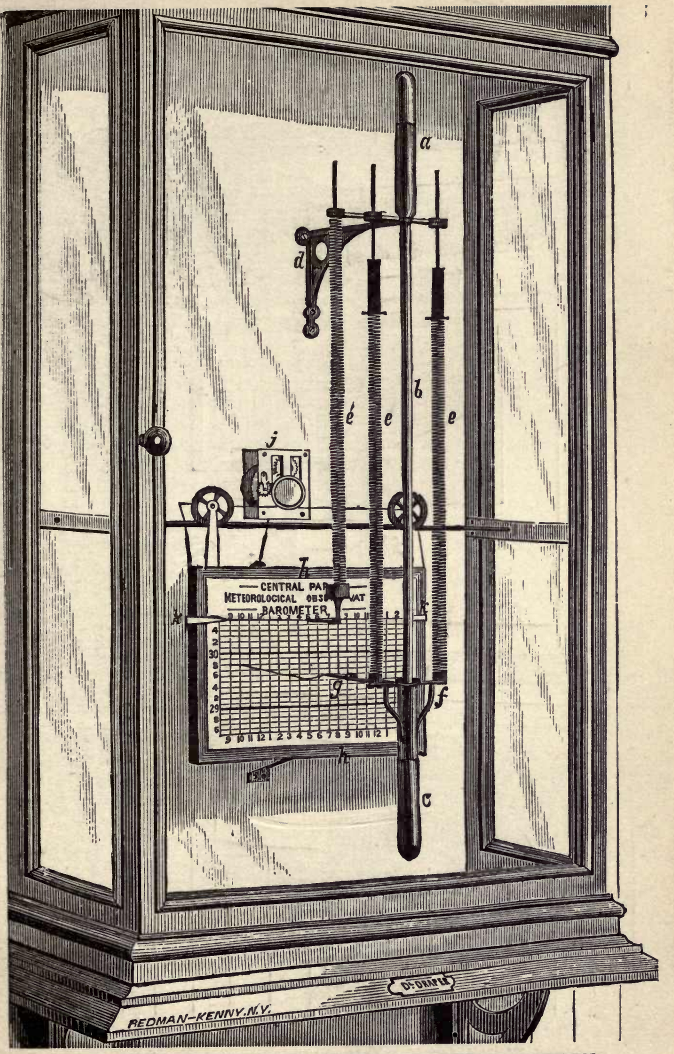
4. A chronograph attachment which is set in motion at the beginning of a shock, and records the time of its occurrence by one of the standard clocks. It also marks the clock seconds upon the revolving plate of No. 1. An instrument by Professor MILNE designed to do the same work as No. 3 is also provided.

A catalogue of earthquake shocks in California from 1769 to 1887 has been compiled, and arrangements looking to a systematic registration of such shocks in various parts of California have been made.

A copy of No. 3 has been made in a cheap form by the California Electric Works (35 Market street, San Francisco) and is sold by them for $15. I hope to see many such instruments distributed throughout the State.

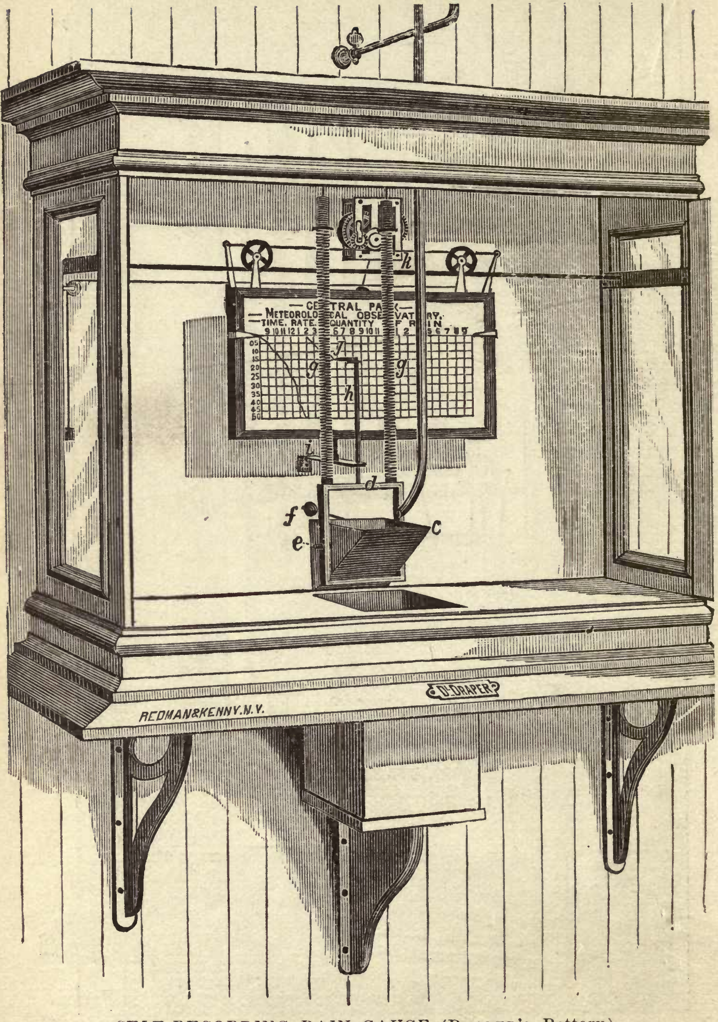
In this description, which is already too long, I have been obliged to pass over many things of real importance, and to merely mention obligations of the observatory to individuals, which ought to be set out in full.

My object in what is here written has been to show the condition of the observatory as regards its fitness for work, and to outline the history of the successive steps by which the desolate summit of a mountain 4,300 feet high has been turned into the site of one of the most important observatories in the world. From the inception of the plan until now, this history will reflect credit on all who have been concerned in the work. MR. LICK made the most splendid gift of the whole world to a noble science. The successive Boards of Trustees were composed of the best citizens of the State. The President of the present Board has given the best ten years of his life to make the observatory a success, and he has been most ably assisted. Astronomers all over the world have given their time and their advice generously without compensation. The Regents of the University have resolved to maintain the observatory in the most liberal and intelligent manner. The press and the public of California have been most friendly to the undertaking.



SELF-RECORDING BAROMETER—(DRAPER'S PATTERN)

As the barometric pressure changes more or less mercury is in the bulb whose weight changes therefore; these changes of weight are registered by the pencil on the moving tablet.



SELF-RECORDING RAIN GAUGE (DRAPER'S Pattern)

As the box becomes fuller and fuller of rain water, it becomes more and more heavy. Its weight extends the spiral springs and causes the pencil to trace a line on the tablet.

VII. THE WORK OF AN OBSERVATORY.

I should like to be able to give a vivid picture of the work of an astronomical observatory; of its daily routine; of the results which it seeks for; of the ideals it keeps in view; of its relation to the community, and, finally, of the relation of each member of the community to it. I do not know how I can do this better than by reprinting here a few extracts from a lecture which I delivered on this subject before the Society of California Pioneers in May, 1887. After giving a brief history of the observatory, and after enumerating its instruments and equipment, which was soon to be complete, I went on to say:

"You will shortly have your grand observatory—that is, the telescopes, the other instruments, the buildings and all the necessary appliances to make the whole of this magnificent outfit useful. Suppose they are all standing there, silent, waiting. What next. There must be a corps of observers to utilize them—to bring out the results they are capable of giving. The Regents of the University have taken a large-minded and liberal view of the situation, and they have appointed a staff of competent astronomers who will do credit to their unrivalled opportunity.

THE WORK OF ASTRONOMERS.

The prevailing ideas about an astronomer's work are singularly erroneous, as they are really inheritances from the days of astrology. It is very commonly supposed that the astronomer's business is to sit at the eye-piece of his telescope in a costume more or less picturesque and outlandish, and to watch the heavens go by and to "make discoveries." Exactly what these discoveries are is usually not stated, but unless a sufficient number are forthcoming the astronomer is held to be blameworthy. There are plenty of discoveries to be made, but the times are changed since GALILEO took his very first look through a small telescope hardly more powerful than an ordinary field glass. He saw that *Venus*, the mother of love, emulated the phases of *Cynthia*, the moon, and by that simple observation overturned the theory that all the planets shone by their own light, and finally that the planets revolved round the earth. You must mark, though, that the discovery was in the astronomer's *interpretation* of his observation, not in the observation itself. Again, GALILEO's discovery of the four satellites of *Jupiter*, HERSCHEL's of the planet *Uranus*, LE VERRIER AND ADAMS' discovery of *Neptune*, HALL's of the satellites of *Mars* — perhaps such as these can never

be repeated. It may well be that there are no more than eight planets—that all the satellites have been already discovered. So it may be that these glaring, obvious and popular discoveries, so to say, are come to a natural limit. I do not say that this is so. I say it may well be so. If there is a satellite more to *Mars* or *Neptune* or a satellite to one of the satellites of *Jupiter* or *Saturn* we may hope to find it. If there is not, the fruitless hours we may have spent in the search for these objects do not show for much. You cannot know how many such hours there are in an astronomer's life. I believe that the elder STRUVE spent twenty years looking for *Neptune*, but it is not even in the books that he looked at all. What we *know* is that in his search for *Neptune* he discovered and measured thousands of double stars, and that he laid the firm foundations of a Science of Double Stars. He said nothing of his unsuccessful search because he found nothing. In that one respect we shall be more fortunate than other possessors of large telescopes. What we cannot see with our telescope, the most powerful of all, in our elevated situation, the best in the world, need not be looked for with inferior telescopes in less favored situations. We shall be justified in publishing our negative results.

Let me give you a picture of what you might see any night in visiting the Lick Observatory, and then let me try to tell you what the meaning of it all may be. You enter a large room lighted feebly by a lamp, and if you stand a moment you can see that somewhere near the center, is a large and complicated instrument, a meridian circle, composed of a telescope, of microscopes, of divided circles. The room is almost perfectly dark except for the feeble glimmer of a hand lamp which the observer carries, and by whose light he examines alternately the face of the clock, whose beats you hear, and the list of the star which he is to observe. Soon you see him point the telescope out through the opening in the roof of the building, and at the expected moment the star he seeks enters the field of view of his telescope. He is already seated, and looking through the eye-piece at the star as it slowly moves along. If your eye could replace his, you would see the star as a brilliant and very small disc—moving slowly and regularly across the field of view and coming up to, crossing and leaving each one of a set of fine spider lines stretched in the eye-piece. As the star crosses each one of these the observer taps a telegraph key, and this tap and the clock-beats are all that you can hear standing where you are. The telegraph key registers a little mark on a revolving sheet of paper in another room among rows of marks made by other telegraph signals automatically sent from the pendulum of the standard astronomical clock, to the chronograph. As soon as the taps have ceased the observer leaves the telescope and writes down five numbers in a little book he carries, and *this* star is "observed." Another and another and another star is observed

in the same way, and thirty or forty such observations make a night's work of this one astronomer. Another and another and another night's work is added to the first one, and so on for years and years. What is the meaning of all this?

In the firstplace let us see what data the observer has gained from his observation of a single star:

On the next morning he consults the register on the revolving barrel and he finds that a certain star has crossed the spider lines in the telescope at *so many* hours *so many* minutes *so many* seconds and *so many* hundredths of a second. He finds from his little book which registers the readings of his microscopes and divided circles that the same star was *so many* degrees, minutes and seconds and decimals of a second from the north pole of the sky. The whole of his night's work on this star has given him two numbers. One number that tells the exact time by his clock, when the star crossed the meridian, and one that tells him the angle between the star and the north pole. Now, these two numbers have to be corrected in various complicated ways by calculation—for refraction, aberration, precession, nutation, and after an hour's computation on each observation he finds two new numbers—and these give him the star's longitude and latitude as they would have been if the star had been observed exactly at the beginning of the year 1875. That is the whole outcome, so far, of the observation of this one star—which took, say five minutes—and of its calculation, which took, say 60 minutes. The thirty other stars "observed" on this night; the thirty stars of 200 other nights in the same year; the 6,000 observations of each of ten years, say, are finally printed in a book. There are only three columns, —one gives the star's name and the two others give its longitude and latitude as they would have been observed had each of the 60,000 observations been made at the exact instant which separates Dec. 31, 1874, from Jan. 1, 1875. That is a catalogue of stars. It has taken a strong and an able man ten, fifteen, twenty years to make, and he is proud of it and glad to sacrifice his ease and his life to it. But how disappointing all this is! What has become of the romantic aspect of that dark and silent room, with its roof uncovered to the stars, with no sound heard but the monotonous beating of the clock; with no light but the feeble glimmer of the astronomer's lamp? Do you think the dignity and romance is all gone? Vanished into two columns of figures? Let us see. First, let me tell you that many and many an astronomer has been content to look no further than this himself. To leave all beyond to others. There have been others, too, who made *their* catalogues of these same stars, it may have been fifty, it may have been a hundred years ago. If we compare two catalogues of the same stars made fifty years apart we shall find that the positions of the fixed stars are not fixed at all. Just such observations as these were made by HIPPARCHUS two thousand years ago, and were

compared with earlier observations than his own, and to him we owe the discovery of the precession of the equinoxes. Just such observations as these were made by the Moors in Spain a thousand years ago, and to them we owe the determination of the laws of astronomical refraction. Just such observations as these were made by JAMES BRADLEY, astronomer royal at Greenwich 140 years ago, and to him we owe the discovery of aberration. One hundred years ago SIR WILLIAM HERSCHEL showed that after all the effects of precession, refraction, aberration, had been allowed for, *still* the stars were not at rest. Each one had what HERSCHEL called a proper motion—one proper and peculiar to the star. The unexplained residual proper motions were examined by HERSCHEL, and he announced his grand discovery that the sun and the whole solar system was whirling through space, away from some of the fixed stars towards others of them. The stars we move away from crowd toward each other by their proper motion, just as the two rails of a railway seem to meet behind a flying train. The stars in front press away from each other as the groups of trees in a forest seem to open as we approach them. Just such observations as these led two of the greatest living astronomers, in Sweden and in Germany, less than five years ago, to suspect that, allowing for all the discoveries of HIPPARCHUS, of AL HAZEN, of BRADLEY, of HERSCHEL, there was yet a motion of all the stars in the sky in a grand vortex parallel to the milky way itself; that every star might be moving in a gigantic orbit swayed by the attraction of that noble galaxy which spans our winter skies. Have I shown you that there is still a romantic aspect, a real dignity, in the numbers which come from the taps of the astronomer's telegraph key, from the inscription of the readings of his divided circles and of his microscopes? Is it not plain that we must not turn away from the silent room where the monotonous routine is unbroken, and say that we are disappointed: If we are disappointed, does it not show that we were simply ignorant? May we not say of the true astronomer, that "to him the fates are known of orbs dim hovering on the skirts of space?" Just such conclusions as these are at the end and on the way in every one of the myriad series of observations will be made at your own Lick Observatory, and at all other observatories this year, this decade, this century; next year, next decade, next century. The day of glaring discoveries, startling announcements *may* be over, as I said before—but the reward of patient, continuous, faithful, intelligent labor is just as sure now, as it has been—as it always will be. I have described to you how catalogues of stars are made with a meridian circle and what they lead to. Similarly many of the observations with the great telescope are just as much apparently mechanical and routine and uninteresting on the surface. Night after night, and year after year, Mr. BURNHAM will measure the angle between the two component stars of a binary system, and

finally we shall compute the period of revolution of one of these suns about another, and their distance apart. Other series of laborious and seemingly mechanical observations will lead to a knowledge of the distance of this system from the earth, and then we can say just how much mass the system has in terms of the sun's mass—just how heavy it is compared to the earth. This has to be done for one system, for another, for another and another, and finally we shall know just what order of magnitudes are to be expected in the scheme of creation.

We have already learned that our sun is a star like other stars, but small among its fellows, though infinitely important to us. Again, suppose the telescope is used to examine the surface of a planet, of *Mars*, of *Jupiter*, of *Saturn*. The astronomer does not sit there and let the planet "drift into his gaze," as the poet has it, but he seeks it out, he questions every aspect of it, not only with his imagination but with carefully planned micrometric measures executed with painful laborious accuracy night after night. It is a refined land-survey by novel methods that he makes, and it is after all only an extremely accurate map that he constructs. There is no way in which an appreciation of the *art* of the practical astronomer can be so quickly and so thoroughly gained as by looking through a large telescope at a planet like *Mars*, for example, and seeing how almost infinitely little detail can be made out in any one view of this minute flaring disc, and then to examine carefully the maps that we have of the surface of *Mars*, where hundreds and hundreds of particulars have been carefully and correctly recorded, as the results of thousands and thousands of hours' work. The first feeling of an amateur in looking at such an object is invariably one of utter disappointment. Where is the promised glory of the heavens? It is not here. Whose fault is it? Should we blame the telescope? our eyes? our minds? or the canopy of heaven itself? WORDSWORTH has asked these—and other—questions in his poem *Star-Gazers*, and he goes on to say—

> Whatever be the cause, 'tis sure that they who pry and pore
> Seem to meet with little gain, seem less happy than before.
> One after one they take their turn, nor have I one espied
> That does not slackly go away as if dissatisfied.

This is the dissatisfaction of inadequate knowledge. More knowledge brings more light, and more light brings deep pleasure and deep satisfaction. As it is with simple looking through the telescope so it is with our spectroscopic observations. It is not the rainbow tinted beauty of the spectrum that we admire, but the minute displacement of its lines that we *measure*, and measure with pain and labor and fatigue, with faithful, conscientious, endless care. Again, in photography, what do you think it costs to produce a map of the stars with our immense camera? It is

not simply to point the telescope, to prepare the plate, to expose it and develop it, for no instantaneous exposures will do here. Our exposures must be for two or three hours successively, and during this whole time the telescope must be made to follow the stars from rising to setting with perfect precision. During all this period the astronomer's eye must be there to see, and the astronomer's hand must be there to correct the slightest deviation in the pointing of the telescope itself. Three hours of exposure will give us a map of four square degrees in the sky. There are more than 40,000 square degrees in the whole sky, so that 10,000 maps are needed to cover it. Say, twenty-five long years, 200 nights in each year, must be spent to cover the sky once only. Art *is* long and life *is* short.

I assume that I have already made it plain what kinds of work we shall undertake at the new observatory, and in a general way how we are going to do it. You will see that it is not going to be a place for idlers—neither for idle astronomers nor for idle guests. If we are to make the Lick Observatory a place which the whole State and the whole country is to be proud of, and to which astronomers of the whole world will come to confirm their previous investigations or to resolve their previous doubts, it is our sacred duty to preserve for ourselves the right to uninterrupted and continuous work. It is only in this way that our real duty to the community can be done, and any other course will be sure to end in dissatisfaction and disappointment.

Mr. Lick's original gift to the Lick Observatory was $700,000. The deed of trust was so drawn that this $700,000 alone was available, and all the expenses of building the observatory have been paid out of this sum; none of the interest which this sum has earned during the thirteen years of the trust is available for the observatory but goes to the residuary legatees, who are the Society of Pioneers and the California Academy of Sciences. More than $575,000 have been expended in leveling off the top of the mountain, constructing waterworks, building all the buildings, providing a water supply, buying all the instruments, etc. There will remain for the benefit of the observatory less than $125,000. The Regents of the University have to invest this in such securities as they can find as

A PERMANENT ENDOWMENT FUND.

From this and from such other funds as the Regents may appropriate, and as may be given by private persons, must be paid all the expenses of the observatory, for salaries, for maintenance, repairs and additions, which requires not less than $20,000 a year, and Mr. Lick's endowment does not produce the half of this. The State of California has generously printed volume one of our publications. It is, perhaps, hardly safe to assume that the State will be willing to continuously print such very technical work always, and

it is of great importance that a publication fund should be established. The publication fund should not be less than $25,000, the interest on which ($1,250) will enable us to publish our work in a suitable manner. It must be remembered that under the most favorable circumstances the State can only pay for such publications as can be printed with ordinary types. One of the principal objects of the observatory will be to make a photographic map of the heavens, by means of the large telescope and its photographic objective. To express the results of this work it will be necessary to publish maps by photo-lithography or otherwise. These maps could, under no circumstances, be paid for by the State, unless by a special appropriation. This photographic work is of immense importance, and the most brilliant results may be expected to follow from it if it is prosecuted intelligently and faithfully. To do this, the observatory should have a fund available for photographic and spectroscopic work only. The largest part of the interest of this fund should be expended in paying the salaries of two persons—one an astronomer who attends to the spectroscopic work and overlooks the photographic operations, the other a professional photographer of the highest skill, who attends to the very delicate photographic manipulation. The best gift that could be made to the observatory would be one which should provide for the salaries of these two men by the interest on a special fund.

THE LIBRARY.

In administering the observatory, the Lick Trustees felt obliged to cut down the appropriation for a library to its very lowest limits. A proper astronomical library should contain some seventeen or eighteen thousand volumes, and should cost about $25,000. The Lick Trustees purchased about two thousand volumes of these, making selection of the ones that are absolutely essential for our work, and have trusted to the generosity of private citizens of California to provide a library for the Lick Observatory, which should bear the name of the donor. A gift of $25,000 outright for the purchase of a large astronomical library, and the provision for an annual income of about $2,000 for subscription to astronomical and mathematical periodicals, and the purchase and binding of books, would be one of the most practical and valuable additions to our equipment. The observatory has been built with a careful eye to its annual running expenses being kept small. It is very completely equipped as to its instruments. Its chief need is, and will be, funds producing an annual income for the payment of enough astronomers to utilize its magnificent outfit.

I trust that I have given something like an adequate view of the Lick Observatory—what it is and what it ought to be. I beg you to remember that it can only become and remain an honor to the State by doing the strictly scientific work for which it was intended

in the best possible manner. Remember that the success of the observatory depends finally upon the observers—upon their skill and upon their number.

I can promise you for myself and for my colleagues that we will spare no labor to bring out all the results which the splendid instruments can give. We will give our whole force—all our efforts and all our lives—to this end. We ask from you your most hearty and loyal support; we feel sure that we shall have it. Secure for us the time to work in, and help us to maintain a sufficent number of observers to fully utilize the opportunity. If you completely understand the case as it is, if you take the large view of it which is the only true view, I feel sure that the Lick Observatory will not disappoint California."

VIII. TELESCOPES.

THEIR HISTORY AND THE DISCOVERIES MADE WITH THEM.

It may not be superflous to give here a brief sketch of the progress and improvement of telescopes, from the time of their invention down to the present day, when the king of them all has just begun his reign. This is perhaps an appropriate place to trace the genealogy and to describe the ancestry of the most powerful telescope in the world.

THE INVENTOR OF THE TELESCOPE.

GALILEO is popularly regarded as the inventor of the telescope, since in his hands it performed such prodigies. But he himself says he got the idea of combining two lenses, to produce an enlarged image of an object, from Holland. There is no doubt that the telescope was invented there by either METIUS, LIPPERHEY or JANSEN, for the States General in November, 1608, refused to grant a patent for such a device on the ground that it was already known and in use for military purposes. GALILEO heard of this invention in 1609, and at once made a telescope, which he exhibited at Venice. It is noteworthy that the telescope was invented for use in war; its applications in science began with GALILEO's return to Florence. Here he made several instruments, some of which I have myself seen. They were on the principle of the ordinary opera-glass, but they were single-barreled. The most powerful only magnified some thirty times and its vision was far from good, since the art of grinding lenses was in its infancy. To understand the revolution that GALILEO's discoveries made, we should comprehend the times in which he lived.

GALILEO'S DISCOVERIES.

The sun was then regarded as pure fire, immovable and immaculate; but GALILEO found spots upon its disc, and showed that it rotated on an axis. Perhaps then, it was the earth after all that rotated on an axis and not the whole universe that turned around nightly to display the glory of the stars to contemplative men. The number of the stars was limited—had not PTOLEMY catalogued them? —and the milky way was just a shining path through heaven. But GALILEO's telescope showed innumerable stars which the eye had never seen and introduced unknown complexities in the place of the simple order which had reigned before. The number of the planets was then seven; the *Sun*, the *Moon*, *Mercury*, *Venus*, *Mars*,

Jupiter, Saturn. But in January 1610, GALILEO found that *Jupiter* was accompanied by satellites in no wise different from our moon. The sacred number seven had become eleven: PYTHAGORAS had not constructed any harmonies with eleven as a basis. There were not eleven studies in the curriculum. The planets themselves were no longer bright points of light, but worlds with discs and faces like the sun and moon. *Saturn*—aged *Saturn*—had servitors to help him on his journey.

Venus in particular resembled the moon in the most special way. Her disc, which at one time was round, became a half-circle, and finally a thin crescent like the new moon. In doubt as to the exact significance of this, GALILEO recorded his doubts and concealed his discovery in an anagram, as follows:

"Hæc immatura a me jam frustra leguntur o. y." That is to say, "These things as yet not ripe are vainly gathered by me." His discovery was hidden in this sentence also, for when its letters are transposed it makes the declaration: "Cynthiæ figuras æmulatur mater amorum"—that is, "*Venus* imitates the phases of the moon.'

RESULTS OF GALILEO'S OBSERVATIONS.

The first observation of GALILEO on *Venus* was made in September, 1610, and the result of it was to prove that the planets revolved round the sun and not round the earth. For centuries, man and the earth on which he lived had been considered the true center of the universe, which, therefore, was made for him. But if *Venus* had phases like the moon, she shone like the moon, by virtue of the sun's reflected light; and it took but a little calculation to show that the observed phases changed as *Venus* revolved round the sun, and were in no way dependent upon the position of the earth. Here, at one blow, the "optick tube" which MILTON saw when he visited GALILEO at Florence, had overturned the theories of centuries and had directed human inquiry along new channels — along the channels, in fact, which the world is following to-day. KEPLER, NEWTON, CUVIER, LYELL, HUXLEY, DARWIN would have been impossible if GALILEO had not struck this first blow. It is important to notice that it was not the observation that GALILEO made, but the interpretation of the observation, that did the work. It was, after all, by a man that man was dethroned as the king and center of the universe. It is precisely the same to-day. Powerful telescopes and grand observatories are of no use unless the facts which they reveal are co-ordinated and interpreted by competent observers. The man is more than half the telescope, and often a discovery has been chiefly valuable, not in and for itself, but as a means to free some master-mind and to give it opportunity. I never see the planet *Uranus* without remembering that its almost chance discovery gave HERSCHEL thirty years of leisure, and that the study of its motions by

ADAMS and LE VERRIER led not only to the discovery of *Neptune*, but also devoted the whole lives of two great philosophers to the service of mankind.

TELESCOPES OF THE SEVENTEENTH AND EIGHTEENTH CENTURIES.

The glasses which were available to GALILEO and his successors were of poor quality and of small dimensions. The largest pieces were only five inches or so in diameter. These were made into object glasses by HUYGHENS (about 1670), and to avoid the aberrations of form and color the focal length of these had to be 40, 50, even 100 feet. The mechanical difficulties of handling such long telescopes were (and are) great. Yet in the hands of CASSINI, HUYGHENS and others great discoveries were made by them. The real nature of *Saturn* and his ring was unfolded; satellites to *Saturn* were discovered; the nebulæ were for the first time seen; the surfaces of all the planets were studied.

The difficulties in procuring glass led NEWTON to the construction of a reflecting telescope in 1668. This was an inch in aperture and magnified thirty-nine times, and its mirror which took the place of the glass objective was made of an alloy of copper and tin. Nevertheless the long and clumsy refractors of HUYGHENS held their own until HADLEY (1723) constructed a reflector only five feet long which was superior to the best of the refractors.

REFLECTING TELESCOPES.

In the last half of the eighteenth century SHORT constructed admirable reflectors, and HERSCHEL began the manufacture of others which surpassed even these. About 1785 HERSCHEL'S twenty-foot reflectors had an aperture of eighteen inches and were instruments of extreme precision.

The advantages of reflectors are found in their cheapness and in the fact that, supposing the mirrors perfect in figure, all the rays of the spectrum are brought to one focus. Thus the reflector is suitable for spectroscopic or photographic researches without any change from its ordinary form. This is not true of the refractor, since the rays by which we now photograph (the blue and violet rays) are, in that instrument, owing to the secondary spectrum, brought to a focus slightly different from that of the yellow and adjacent rays, by means of which we see. Reflectors have been made as large as six feet in aperture, the greatest being that of Lord ROSSE, but those which have been most successful have hardly ever been larger than two or three feet. The smallest satellite of *Saturn* (*Mimas*) was discovered by Sir WILLIAM HERSCHEL with a four-foot speculum, but all the other satellites discovered by him were seen with mirrors of about eighteen inches in aperture. With these the vast majority of his other discoveries were made. The satellites of *Neptune* and *Uranus* were discovered by LASSELL

with a two-foot speculum, and much of the work of Lord ROSSE has been done with his three-foot mirror, instead of his more celebrated six-foot one.

From the time of NEWTON till quite recently it was usual to make the large mirror or objective out of speculum metal, a brilliant alloy liable to tarnish. When the mirror was once tarnished through exposure to the weather, it could be renewed only by a process of polishing almost equivalent to figuring and polishing the mirror anew. Consequently, in such a speculum, after the correct form and polish were attained, there was great difficulty in preserving them. In recent years this difficulty has been largely overcome in two ways: First, by improvements in the composition of the alloy, by which its liability to tarnish under exposure is greatly diminished, and, secondly, by a plan proposed by FOUCAULT, which consists in making, once for all, a mirror of glass, which will always retain its good figure, and depositing upon it a thin film of silver, which may be removed and restored with little labor as often as it becomes tarnished.

In this way one important defect in the reflector has been avoided. Another great defect has been less successfully treated. It is not a process of exceeding difficulty to give to the reflecting surface of either metal or glass the correct parabolic shape by which the incident rays are brought accurately to one focus. But to maintain this shape constantly when the mirror is mounted in a tube and when this tube is directed in succession to various parts of the sky, is a mechanical problem of extreme difficulty. However the mirror may be supported, all the unsupported points tend by their weight to sag away from the proper position. When the mirror is pointed near the horizon the flexure is one thing; it is quite a different thing when the telescope is pointed near the zenith.

As long as the mirror is small (not greater than eight to twelve inches in diameter), it is found easy to support it so that these variations in the strains of flexure have little practical effect. As we increase its diameter up to 48 or 72 inches the difficulties become almost insurmountable. In fact no good mirror has been made larger than 36 inches. Mr. COMMON, of England, is now engaged on a large reflector of 60 inches aperture, and if any one can make such a mirror successful it is he. But up to this time his 36-inch mirror is the largest reflector which has been really successful.

THE ACHROMATIC TELESCOPE.

Although refractors of the simple form used by HUYGHENS were wonderful instrument in their day, yet they would not now be regarded as satisfactory owing to the aberrations with which a single lens is affected. When ordinary light passes through a simple lens it is partially decomposed, the different rays coming to a focus at different distances. The focus for

red rays is most distant from the object-glass, and that for violet rays the nearest to it. Thus arises the chromatic aberration of a lens. But this is not all. Even if the light is but of a single degree of refrangibility, if the surfaces of a lens are spherical the rays which enter the edges of the lens will come to a focus quicker than those which enter near the center. This latter defect of spherical aberration was partly cured by the enormously long focused lenses constructed by HUYGHENS.

But of the two defects, the chromatic aberration is much the more serious ; and no way of avoiding it was known until the latter part of the last century. The fact had, indeed, been recognized by mathematicians and physicists, that if two glasses could be found having very different ratios of refractive to dispersive powers,* the defect could be cured by combining lenses made of these different kinds of glass. But this idea was not realized in practice until the time of DOLLAND, an English optician who lived during the last century. This artist found that a concave lens of flint glass could be combined with a convex lens of crown of double curvature in such a manner that the dispersive powers of the two lenses should neutralize each other, being equal and acting in opposite directions. But the crown glass having the greater refractive power, owing to its greater curvature, the rays would be brought to a focus without dispersion. Such is the principle of the construction of the achromatic objective. As now made, the outer or crown glass lens is double convex ; the inner or flint one is generally nearly plano-concave.

CONTEST BETWEEN REFLECTORS AND REFRACTORS.

The struggle for supremacy between reflectors and refractors, which began before the time of HERSCHEL (1750) is not yet concluded, but by the invention of the achromatic combination of DOLLAND the refractor was placed on equal terms. About 1800 the four-inch telescopes of DOLLAND were successfully competing with much larger reflectors of that day. In 1830 the manufacture of glass had improved so far that objectives of nine inches and more could be made ; and several of about that size were constructed for the observatories of Dorpat, Rome and Munich by FRAUENHOFER, the successor of GUINAND. There was nothing which could be seen by the forty-foot reflector of HERSCHEL which was not equally well seen by means of these far more convenient instruments. The form of their mounting was also vastly improved and the permanence of their adjustments was a capital advantage.

When FRESNEL invented the modern system of lighthouse illumination the demand for good glass became very great, and in this

*By the *refractive power* of a glass is meant its power of bending the rays out of their course, so as to bring them to a focus. By its *dispersive power* is meant its power of separating the colors so as to form a spectrum, or to produce chromatic aberration.

case as in others every advance made in the service of the arts was quickly utilized by science, which had given the original impetus. The refractor became the standard instrument, while the reflector did wonders in the hands of a few observers, who made their own instruments and who knew how to obviate each one of the many difficulties in their use. The 15-inch telescopes of Harvard College and of St. Petersburg remained the most powerful refractors from 1845 to 1861. In the mean time, the two-foot reflector of LASSELL had made numerous and important discoveries. The satellites of *Uranus* and *Neptune* were discovered by its aid, and Mr. BOND, at Harvard College, anticipated LASSELL'S discovery of the seventh satellite of *Saturn* by a few hours only.

THE TELESCOPES OF ALVAN CLARK.

The refractors made by ALVAN CLARK (1845–60) were of extreme excellence, and some of his smaller telescopes (7 and 8 inches) had found their way to England. In 1861 the CLARKS made a telescope of 18 inches aperture. In 1873 the 26-inch refractor of the Naval Observatory at Washington was mounted and soon proved itself to be a master work. No other telescope in the world has done so much and so brilliant work in the fifteen years just passed. A duplicate of this was made by the CLARKS for the University of Virginia, one nearly as large (23-inch) for Princeton, then a 30-inch for St. Petersburg and finally the 36-inch for the Lick Observatory.

The most important matter in a telescope is perfect definition, *i. e.*, neatness, accuracy in the image of the object looked at. This allows the use of high magnifying power provided there is light enough collected by the object-glass. It is precisely in respect of definition that the Clark telescopes are pre-eminent.

LIGHT-GATHERING POWER.

It is not merely by magnifying that the telescope assists the vision, but also by increasing the quantity of light which reaches the eye from the object at which we look. Indeed, should we view an object through an instrument which magnified but did not increase the amount of light received by the eye, it is evident that the brilliancy would be diminished in proportion as the surface of the object was enlarged, since a constant amount of light would be spread over an increased surface; and thus, unless the light were brilliant, the object might become so darkened as to be less plainly seen than with the naked eye. How the telescope increases the quantity of light will be seen by considering that when the unaided eye looks at any object, the retina can only receive as many rays as fall upon the pupil of the eye. By the use of the telescope as many rays can be brought to the retina as fall on the entire object-glass. The pupil of the human eye, in its normal state, has a diameter of about one-fifth of an inch; and by the use of the telescope the retina is virtually increased in surface in the ratio of the square of the

diameter of the objective to the square of one-fifth of an inch. Thus, with a two-inch aperture to our telescope, the number of rays collected is one hundred times as great as the number collected with the naked eye.

THE POWER OF THE EYE AND OF THE TELESCOPE CONTRASTED.

If the brightness of a star seen with the eye alone is 1, with a 2-inch telescope it is 100 times as bright, with a 4-inch telescope it is 400 times as bright, 8-inch telescope it is 1,600 times as bright, 16-inch telescope it is 6,400 times as bright, 32-inch telescope it is 25,600 times as bright, 36-inch telescope it is 32,400 times as bright. That is, stars can be seen with the 36-inch telescope which are 30,000 times fainter than the faintest stars visible to the naked eye. While the magnifying power which can be successfully used on a 5-inch telescope is not above 400, the 36-inch telescope will permit a magnifying power of more than 2,000 diameters on suitable objects, stars for example. This power cannot be used on the moon and planets with real advantage for many reasons, but probably a power of 1,000 or 1,500 will be the maximum. The moon will thus appear under the same conditions as if it were to be viewed by the naked eye at a distance of say 200 miles. This is the same as saying that objects about 300 feet square can be recognized. So that no village or great canal or even large edifices can be built on the moon without our knowledge. Highly organized life on the moon will make itself known in this indirect way if it exists.

If one were looking at the earth under the same conditions, the great works of hydraulic mining or the great operations on Dakota farms or California ranches would be obvious.

LARGE TELESCOPES.

A great enemy to large telescopes, and indeed to all telescopic vision, is the unsteadiness of our own atmosphere. It is just in this respect that the site for the Lick Observatory has been well chosen. We are sure that we can use higher magnifying powers to advantage there than at any other stations. Whatever advantages belong to large telescopes (and there are many), we shall come nearer to realizing there than at other sites. We have lately heard much of the disadvantages and failures of large telescopes, in some cases from persons who are not skilled in their use. It will be far more satisfactory to point to the results of observations at Mt. Hamilton than to dogmatize about what those results are to be. If we stop to inquire what results we might like to hear of, we may see that some of them are unlikely to be reached or impossible of attainment. Mr. LICK wished to prove or disprove the existence of animals in the moon. If there are city building animals we shall know this indirectly. We should all like to know if *Neptune* is the last planet of our system, but this is probably not a question

for large telescopes at all, but one for photographic maps of the sky to settle. If there are more faint satellites we ought to be able to see them, and so with many other similar problems.

But leaving such questions to one side for the present, let us consider the subject in another way. The whole earth is dotted with powerful telescopes in the hands of able astronomers. There is not a single telescope so powerful as our own; there is no one so advantageously situated; some of our observers are the equal of any on the globe. There will be a natural limit to the performance of other telescopes, and that limit will yet remain within our powers. In this very simple way the Lick telescope will become the final arbiter in very many important and difficult questions. If it does no more than this and if it does this well and faithfully it will justify its existence and all the labor that it has cost. What it does more than this will be still more to its credit.

THE PHOTOGRAPHIC OBJECTIVE

I have spoken elsewhere in this book of one of the chief adjuncts of the great instrument—namely the photographic lens of 33 inches aperture, which Mr. ALVAN G. CLARK has lately completed. When this is applied to the large telescope it converts it into a gigantic photographic camera.

The automatic records which this will give of the features of the moon, the planets and the stars, will unquestionably be far beyond what has been attained elsewhere. I prefer in this case also to point to results actually attained rather than to say what they are likely to be.

IX.

THE UNMOUNTED LENS

OF THE

GREAT TELESCOPE AT MOUNT HAMILTON.

By **A. V. G.**

I.

Mysterious Eye, dim shrouded from the light,
Bound with dark bands like Lazarus in his tomb,
Shut in by muffled doors from sight and sound
Of the world's outer life, soft speech of men,
And neigh of steed, and tramp of busy feet;
No sound about thee save the sullen wind
That moans and raves around thy mountain crypt;
No light save thine own inward radiance
That links thee with the space-embosomed stars:
Close-lidded sleep'st thou in thine inner court
Of dark and silence the while men do forge
With bolt and rivet and strong bands of steel,
The mighty orbit for thy wondrous sphere.
Know'st thou thy power? Dost feel thy destiny?
Beneath these grave-like cerements thrill'st thou not
Thro' all thy bright circumference with dim
Prophetic visionings of the Abyss
That from gray evening till the purple dawn,
From dawn until the evening gray, will smite thee
With awful splendors of uncounted suns?
O mighty Eye! say what wilt thou reveal,
When from the tomb men Christ-like bid thee forth,
Unbind thy bands, and set thee like a star
Upon Earth's grave and cloud-encircled brow,
Eye unto eye with heaven's dread mystery,
Lidless against intolerable light?

II.

O blindfold, O enfettered, now hath Time
Unto its golden fullness come—along

The dim horizon glows the dawn—awake,
O slumber-held; unclose, O wondrous Eye;
A world awaits the breaking of thy sleep.
O bright Evangelist come forth! Earth's way
Lies lonely thro' the trackless void; a waste
Of cloud and storm, and darkness vast and deep,
Betwixt her and the stars, and far beyond
The farthest glint of star lies Heaven—so far
We cannot see the road the souls must tread
Who thither go. Perchance that thou mayst span
The gloomy sea, and set the Gates of Death
A little way ajar. Perchance that thou
With cloudless vision slowly sweeping up
The mighty Nave that cleaves the galaxy,
God's visible Tabernacle in the skies,
Star-built from shining undercroft to dome,
Past pillared pomp of worlds, and columns wrought
With fair entangle of amethyst and pearl,
Thro' jacinth portals hung with mist of stars,
And fiery fringe of suns—mayst come at last
Even to the Chancel of the Universe;
And so thro' glories veiled and far, behold
The Choral Stars that sang so loud and sweet
On the first Morning when Creation sprang
In dewy beauty from Jehovah's hand.
Mayhap that thou, with swiftness unconceived,
Wilt overtake the light and see the things
That have been, and that shall be nevermore;
Follow the dying star in her swift flight
Athwart Eternity; track the lost world,
That drifting past our ken, still gleameth fair
Upon the confines of some far off realm;
Perchance the Star which first spake peace to men
Will dawn through thee upon the waiting earth;
And O far-seeing Eye, perchance mayst thou
Reveal the City Beautiful which lies
Foursquare in midst of heaven, whose shining walls
Are of fair jasper builded and pure gold;
Whose battlements are crystal, and whose ways
Are sapphire-paven, and whose gates are pearl.

III.

Thou answerest not; but this we know—that thou
Wilt lift the world one step anearer heaven.
Thou art the topmost pace of that vast stair,
Builded by Titan souls up thro' the gloom

Of churchly tyranny and priestly scorn;
Still standeth Galileo at the base,
Forever, straining his grand sightless eyes
Towards the light, groping with shackled hands
For the next step, where Newton stands and weighs
The Universe. Slow climbed those God-like souls,
Building this mighty stairway as they went
One step between the cradle and the grave.
Leverrier set this landing, whence he saw
Uranus swerve a hair-breadth from its path,
And cried, "A world! a world! no eye has seen,
Behold 'tis such a weight, 'tis such a size!"
And lo! the world is there—and Herschel, this—
Grand, patient Herschel, watching thro' the years
The rythmic revolutions of the spheres,
Seeing in the store house of the Infinite,
The star-dust of the uncreated worlds.

IV.

Through thee will Holy Science, putting off
Earth's dusty sandals from her radiant feet,
Survey God's beauteous firmament unrolled
Like to a book new-writ in golden words
And turn the azure scroll with reverent hand,
And read to men the wonders God hath wrought.
Gazing thro' thee, her eye will wander o'er
Infinity's illimitable fields
Where bloom the worlds like flowers about God's feet;
Rose worlds and purple suns, and seas on seas
Of lily stars that make a way of light,
And golden orbs that border all the way,
And meadows fair of greenest emerald,
And billowy seas that palpitate and flash
Now seen, now lost beyond all vision's ken;
Where, cradled on the glowing ether, swings
As 'twere our Lord Christ's blue forget-me-not,
The planet-petaled blossom of our sun,
That mystic flower, whose filaments of flame,
From burning anthers fling life manifold,
And bloom and beauty on its crown of worlds;
Where, striving o'er the dim ethereal plain,
Orion brandishes his flaming sword
And shakes ajar the awful vestibule
Of heaven's stupendous treasury of suns
Set for a jewel in the mighty hilt.

V.

O patient hands that wrought this crystal pure,
Rest now, 'tis meet that ye should rest, O touch
More soft than down that swathes the eider's breast,
More delicate than the Virgin's threads that float
Athwart the sunshine on a summer's morn.
No grosser toil shall henceforth thee engage—
No grander task remaineth—therefore rest.
O patient hands! we bless you, seeing how
Ye bridged for us the fair and starry way;
O quiet hands! we kiss you where ye lie
Enfolden in a calm and perfect rest;
For death hath touched you lightly, lovingly,
And clothed you with a beauty unbeheld,
Even as ye touched, so light, so lovingly,
This lucent sphere and made it clear and pure—
The world's one matchless gem. Rest gentle hands!

VI.

And thou who didst conceive the mighty thought—
This marvellous window of the world's vast soul—
Who walked the ways of dull and sordid men
Nor asked the world for love, nor sought its praise;
Who, scorning ease, wrought early and wrought late
That thou might'st leave a legacy of Light
To all the generations yet to come;
While dull of heart and brain, men did not know
How with them walked a messenger of God,
Until Death clove the mortal husk and showed
The Soul magnificent within—until
The toil-worn hands relaxed and showed them Heaven.
Thou art more grandly sepulchered than kings.
No obelisk of old, nor sculptured pile,
Nor oriel stained, in dim Cathedral Fane,
So fair as this Memorial Window set
In God's vast Temple, builded not with hands;
Across its disk the armies of the skies
Will pass with jeweled feet slow moving to
The solemn Miserere of the night;
Above thee, mirrored fair, the Morning Star,
Will lead the Hallelujahs of the dawn;
Earth's wise and good will gather at thy shrine
And link thy name forever with the stars.

VII.

Priest-ministrant within this mighty Fane,
Whereon thou standest now is holy ground;
Divinest gift is thine—to gaze the first
On glories yet unseen by mortal eyes.
Gird up thy loins, clothe thee with righteousness,
Cast the world's glamour from thee and its cares;
And if thine eye be single, thy heart pure,
Perchance in the still watches of the night
When slumber lieth on the eyes of men,
Thou'lt catch the effulgent shadow of His feet,
As walking in His garden in the cool,
He plucks some world that bursts to sudden bloom
Of beatific life beneath His hand.
Not death, as men do say—naught dies—the soul
Looks from the windows of her falling house
Calm with the reflex of some fairer sphere;
So worlds die not: sublimed by touch divine,
Their beauty and magnificence depart
To brighter realms; or viewless grown to eyes
Too weak to bear the excess of light which veils
The Throne-place of the glory of the Lord,
In fair invisible orbits softly sweep
To unimagined harmonies of sound
Around the Central Glory, whither tend
Suns, moons and stars and all the hosts of heaven,
Things seen and things invisible and past,
All beauty and all truth, all harmony—
All things that be and all that are to be,
Life beyond Life, Time and Eternity.

SUMMIT OF MOUNT HAMILTON, LOOKING SOUTH FROM MT. KEPLER.
(From 'The Century" for May, 1886.) (The 75-foot Dome was not built when this view was taken.)

X. ASTRONOMICAL PHOTOGRAPHY*.

In order to appreciate the present state of Astronomy, its new methods, its novel instruments, its recondite problems, it is necessary to glance at its condition a half a century ago. The great astronomers, BESSEL and W. STRUVE, were then contending in friendly rivalry to found the science on a sure basis. They had a perfectly definite object, and that object has been attained through their efforts, and through the efforts of the school of young men whom they trained either directly or indirectly — ARGELANDER, SCHOENFELD, KRUEGER, AUWERS, WINNECKE, WAGNER, SCHIAPARELLI in Europe, WALKER, COFFIN, HUBBARD, GOULD in America.

The attention of astronomers was then almost exclusively directed to the question of the *motions* of the heavenly bodies, as determined by the law of universal gravitation. The vast catalogues of stars which have been made in the past half century, as well as the accurate discussion and re-discussion of the older observations of BRADLEY (1750), at Greenwich, were all undertaken for this sole object. The school of mathematical astronomers founded by EULER, LAPLACE, LA GRANGE, GAUSS, utilized these observations to the utmost. The examination of the surfaces of the planets was an entirely secondary question, and was largely left to amateur astronomers. The surface of the sun was studied only in the crudest manner, simply for the enumeration of the solar spots.

The fact that these spots were periodic, was only established in 1851. Sir JOHN HERSCHEL was almost the only astronomer by profession who devoted himself to observations not "of precision."

In this last fifty years, an entirely new science has arisen—Astrophysics—which is, indeed the daughter of Astronomy, but the cousin-german of Chemistry, Technics, Physics.

This new science always had its cultivators, even before it had a name. The elder HERSCHEL set himself the problem "to find out the construction of the heavens," and this is the problem of Astrophysics, in contradistinction to the problem of exact Astronomy — "to find out how the heavenly bodies move." The modern form of HERSCHEL'S phrase is, "to determine the present constitution and the evolution-history of the stars, the comets, the sun, the planets."

We must regard Sir WILLIAM HERSCHEL as the founder of the science. He has had great followers: — SCHROETER, Sir JOHN HERSCHEL, BEER, MAEDLER, FRAUENHOFER, KIRCHHOFF, BUNSEN, LAS-

*This section originally appeared in the *Overland Monthly* for November, 1886, under the title: Photography the Servant of Astronomy.

SELL, BOND, DE LA RUE, RUTHERFURD, DRAPER, SCHIAPARELLI, VOGEL, JANSSEN, LOCKYER, YOUNG, LANGLEY, PICKERING, not to speak of a host of other familiar names.

To-day there are several observatories devoted exclusively to the new science, and their number is growing. This should be so. There are too many astronomical observatories which are idle. If the charm of the new fields is enough to make them efficient in forwarding the science as a whole, we must welcome the new impetus. But there is a note of warning to which we must give attention. We must keep strictly before us the *methods* by which the older astronomy has arrived at its proud position as the chief of the physical sciences. For hundreds, yes, thousands of years, one principle has run through all of Astronomy. Assiduous observations must be made according to well-considered plans, matured after deep reflection. The results of these observations must be compared with a theory expressed rigorously in the terms of mathematics. The differences between observation and theory must be treated by a profound analysis, so to derive corrections to the provisional theory. This provisional theory must in its turn become the basis of comparison with nature, and so on, until the ideal is reached by successive approximations. This ideal is simple and in many researches it has been attained already. It is reached when we have pushed the successive approximations so far that we can *predict* the position or the motion of a heavenly body as accurately as we can *observe* it. When this stage is reached we may leave the special problem in hand, until the methods of observations are themselves improved.

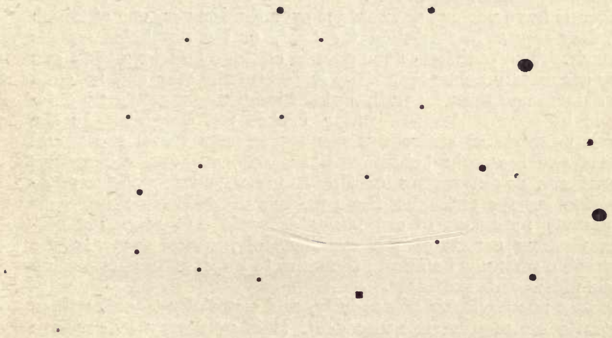
If Astrophysics will accept this ideal and strive for it, there is no future so brilliant that we may not claim it for her portion. If this straight and narrow way is departed from, although the new science is followed never so assiduously, no essential progress can be expected, and real harm is sure to follow.

Astrophysics has three well marked lines of research, namely: *Spectrum Analysis* (now a quarter of a century old), *Celestial Photometry* (half a century), *Celestial Photography* (dating back exactly forty-six years). SCHIAPARELLI'S theory of meteor-streams and their connection with comets, belongs to this science in so far as it throws light upon the material out of which comets are built; and every part of physics which treats of the action of one body upon another body at a distance, whether through gravitation, heat, magnetism, electricity, has close relations to it. But the three main paths are Spectroscopy, Celestial Photometry, and Celestial Photography. It is of the latter path that I speak at this moment. We shall follow it assiduously at the Lick Observatory, and we shall have unrivaled opportunities to do so.

Spectroscopy in certain of its lines, we shall also follow, and our opportunities in this branch also are unique. Photometry is so

thoroughly done at the Harvard College Observatory that it would be a waste of energy for another American observatory to devote any great part of its time to such researches.

I assume that some slight explanation of the differences between a photographic telescope and an ordinary one, will not be superfluous. The object glass of an ordinary telescope brings the rays by means of which we *see* (those having a wave-length of about 6,000 ten-millionths of a millimetre), to an accurate focus. These cannot be photographed except by special plates and with special difficulty. The rays which affect the photographic salts of silver have a wave-length of about 4,000 ten-millionths of a millimetre, and to bring these special rays to a focus, the two lenses of the ordinary achromatic object glass must be supplemented by a third lens. This third lens is so arranged that it can be placed in front of (and close against) the ordinary objective, and it turns the telescope from a seeing instrument into a camera. It is also necessary to say that if the telescope remains fixed, while a bright star is passing across its field of view, the image of the star will pass across the sensitive plate, and will leave a "*trail*" which is the visible representative of the direction of the star's diurnal motion; that is, of its motion from rising to setting. Equatorial stars as faint as the 8th or 9th magnitude will give *trails*.



If, on the contrary, we attach an accurate driving clock to the telescope, and cause it to follow the star in its motion from east to west, we shall have instead of a trail, a bright point, the photographic *image*. If we wish to make a *picture* of the sky, we must register the stars by such points as these.

The figure page 83 may serve to illustrate the meaning. We can point the large telescope at the sky with its photographic third-lens in front of the ordinary object glass and attach the driving clock so as to cause the tube always to point accurately to the same group of stars as it moves from east to west—from rising to setting. We can put a sensitive plate in the proper position and expose it to the stars just as we expose a plate to a landscape. Only in this case the exposure must be very long, from 5 or 10 seconds to an hour or so, depending upon how faint and feeble the light of the stars may be. When the plate is developed we shall have a picture of the sky — a star map. Each star will appear of its proper relative brightness and in its proper relative position. Suppose we had not attached the clock; what would have been the result? Each star would have moved from east to west — from rising towards setting, across the field of view — across the sensitive plate. The image of each star would have rested only for a moment upon any particular portion of the plate—perhaps not long enough to make any impression at all. Hence the fainter stars would have left no trace whatever of their existence. The brighter ones would each have left a *trail*—a succession of instantaneous images like this:

....

This *trail* will represent the direction of the star's motion from east to west perfectly. It is in this way, indeed, that we determine the east and west line on our plates.

The trails have various advantages over the images, one of which is that they cannot be mistaken for dust, or for pin holes on the plate itself. The position of the dots in latitude and longitude can be very accurately measured. The *latitude* of the star can be even better determined from its trail, but its longitude must then be determined by special devices, which I need not describe. In the ordinary methods of observing, the astronomer views the visual images of the heavenly bodies with his eye, and either examines their surfaces, or determines their positions with reference to adjacent bodies (as for example, the positions of satellites relative to their planet), by means of extremely accurate and refined micrometers, forming a part of the eye-piece of his telescope. In the photographic methods he allows the stars to impress themselves on negative plates automatically.

To utilize photographic plates fully, and especially to make them a substitute for micrometric measures, it is necessary to contrive elaborate measuring engines to take the place of the costly micrometers, ordinarily used with telescopes. These engines measure the positions of the dots or trails on the plates, after they have been removed from the telescope.

Mr. RUTHERFURD first made a satisfactory engine of this kind; it was then improved upon in the design of Professor HARKNESS

adopted by the U. S. Transit of Venus Commission, in 1874, and the Lick Observatory owns the finest specimen of this class, which was made for it under the personal supervision of Professor HARKNESS. This can be seen in the instrument-room of the observatory.

The very first essay in Astronomical Photography was that of Professor JOHN WILLIAM DRAPER, of New York, who in the year 1840, took a satisfactory daguerreotype of the moon. The experiments of Dr. DRAPER were repeated by GEORGE BOND, Director of the Harvard College Observatory, in 1850, and a lunar daguerreotype made by him was exhibited at London in 1851, at the World's Fair, where it attracted much attention.

During the years 1853 to 1857, Mr. DE LA RUE, of London, made lunar daguerreotypes and photographs, some of great excellence. In 1864, Dr. LEWIS RUTHERFURD, of New York, constructed an eleven and one half inch objective, which was corrected *only* for the photographic rays, and by means of this he obtained the finest photographs of the moon which have yet been made. Dr. HENRY DRAPER, about the same time, made a fifteen inch reflecting telescope with which he also took excellent lunar photographs. These latter have been enlarged to three and even to four feet in diameter, from the original picture of about two inches and a half. A long-focus telescope is of great advantage in these researches. The pictures in the principal focus of the great Melbourne reflector are some six inches in diameter, and I have seen a few of these of great excellence. Such pictures can be enlarged in printing, from six to twelve times. The photographs of the moon in the focus of the Lick equatorial, will be five inches in diameter, and will probably stand an enlargement of twelve times, so as to be five feet finally. Lunar photographs have not advanced our knowledge in any important degree up to this time, however, though I hope for something from them.

Solar daguerreotypes were first taken by FOUCAULT and FIZEAU in 1845 at Paris, on the advice of ARAGO. In 1857, Mr. DE LA RUE contrived the Photoheliograph for the Kew Observatory, by which solar photographs have been taken since that time daily at Kew and Greenwich.

Mr. JANSSEN of Meudon, near Paris, about 1878, succeeded in making his exquisite photographs of the sun on glass, which show an astonishing amount of detail. I understand that these are chiefly made by means of a six-inch refractor, and I have never been able to comprehend how so much detail can be shown with an objective of such a small separating power, nor to rid myself of an impression that some, at least, of these details are due to atmospheric disturbances. A telescope of a certain aperture can only *separate* two dots of light when they are no closer together than a certain definite angle. A telescope of twice the aperture will separate dots of half this distance and so on. It almost seems as if

some of the beautiful Meudon photographs went beyond this theoretic limit. If the exposures are made extremely short ($\frac{1}{2000}$ to $\frac{1}{1000}$ of a second), very successful results can be obtained in solar photography. There is, undoubtedly, an important field of research still open here, especially with large objectives of great separating power.

The first photographs of a solar eclipse were made by BUSCH, at Koenigsburg, in 1851, and by BARTLETT at West Point, in 1854; but these where merely interesting experiments. The eclipse photographs of DE LA RUE in 1860, were the first of real scientific importance, since they established beyond doubt the fact that the solar protuberances were really appendages of the sun and not of the moon.

I believe the first photograph of the *spectrum of the Sun* at a solar eclipse was taken at the Egyptian eclipse of 1882, by Professor SCHUSTER, and also by the party under Mr. LOCKYER. Very perfect photographs of the solar spectrum were taken at the total eclipse of 1883 in the Pacific Ocean, by the English parties and by the French parties, and the subject does not now present any great difficulties.

Photography served a very useful purpose in its application to the transits of *Venus* of 1874 and 1882. The photographs of both these transits, taken by means of the horizontal photoheliograph, invented by LAUSSEDAT and WINLOCK, and used by the United States observing parties, were of extreme value, and it is probable that the values of the solar parallax derived from the American photographs at these two transits will be found to be extremely near the truth.

According to Professor PICKERING, the first *daguerreotype of a star* was taken at Harvard College Observatory, on July 17th, 1850, under the direction of the elder BOND. The star *Vega* was satisfactorily daguerreotyped, and later the double star *Castor* gave an elongated image, which was plainly due to its two component stars. The sensitiveness of the daguerreotype plates then in use was so small that even such bright stars as these gave faint images, and no impression whatever was obtained from the pole star, no matter how long the exposure. These experiments were repeated with various stars and clusters, but finally the work was abandoned on account of the photographic difficulties. In 1857 the younger BOND resumed the research. At this time the collodion process had greatly reduced the time of exposure, and the plates were of much greater sensitiveness. An impression of the double star *Zeta Ursae Majoris* was obtained in eight seconds. A *trail* was obtained from the image of the bright star *Vega*. The faintest star photographed was the companion of *Epsilon Lyrae*, which is of the sixth magnitude, that is, just visible to the naked eye.

A series of measures was made of the relative positions and distances of the various double stars photographed, in order to see whether measures made upon a photographic plate could be used to replace those made in the ordinary manner at the telescope. It was found that a single measure made upon the plate was about of the same value as a single measure made by an astronomer with the ordinary micrometer. Professor BOND pointed out very clearly how photographic images might be used to determine accurately the relative brightness of stars, and also what the advantages of photography were for the permanent registration of star positions. Mr. DE LA RUE and Doctor RUTHERFURD soon after repeated these experiments of Professor BOND, and a very extended investigation was undertaken in 1864 by Doctor RUTHERFURD, and continued by him for many years. Most of the principal clusters in the northern heavens were photographed, as well as most of the brighter double stars. These researches have never been fully utilized for the following reason; the photographs were measured in the most careful manner on a measuring engine, in which the distances of one star from another were determined by means of a very accurate screw. After the series of measures had been continued for several years, it was discovered that the screw itself had worn considerably, so that the value of its revolutions was not the same as it had formerly been. It was impossible to discover at what time this wear commenced, nor how it progressed, and therefore these excellent photographs have remained undiscussed up to the present time. The distances, which must be accurately measured, are about $\frac{1}{50000}$ of an inch. The faintest stars shown in Doctor RUTHERFURD'S eleven-inch telescope are about of the ninth magnitude. The plates used by Doctor RUTHERFURD were, I believe, exclusively wet plates.

Doctor HENRY DRAPER attacked the same problem in 1880, using, however, the most sensitive dry plates then available In 1881 with an eleven-inch refractor constructed by the CLARKS, he obtained a photograph of the *Nebula of Orion*, in which one of the stars is shown whose magnitude is not more than 14½. This star is barely visible with a telescope of the same aperture as that with which the photograph was taken. The photographic plate now had become as efficient an instrument of research as the eye itself. Mr. JANSSEN also photographed the *Nebula of Orion* in 1881; but the best of all such photographs has been made by Mr. COMMON, of England, with his three-feet silver-on-glass reflector.

Doctor B. A. GOULD, in his expedition to the southern hemisphere (1870–1884), carried with him a photographic lens of eleven inches aperture, and during his entire stay of more than ten years, employed all the available time at his command in accumulating negatives of the principal southern double stars and clusters. These photographs have not yet been discussed, and Doctor GOULD has discovered that

there are signs that the films on the negatives (from wet plates) are now beginning to deteriorate. Probably this extensive and important series will soon receive discussion.

The Royal Astronomer at the Cape of Good Hope, Doctor GILL, has undertaken to make a map of the whole southern heavens, by photographic means only. The Rev. T. E. ESPIN, of Liverpool, has published a catalogue of the magnitudes of 500 stars, determined by means of photography alone. Mr. ISAAC ROBERTS, of Liverpool, has also done capital work of the kind with his reflecting telescope. The most extensive investigation is that of the brothers PAUL and PROSPER HENRY, of the Observatory of Paris. Important investigations have also been made at the Astrophysical Observatory of Potsdam, and at two Physical observatories in Hungary.

In 1863, Doctor HUGGINS, of London, obtained a photographic image of the *spectrum of Sirius*, but no lines were visible in this spectrum. The first successful photograph of the spectrum of a star was obtained by Doctor HENRY DRAPER, in 1872. Each of these astronomers succeeded in 1876 in obtaining valuable spectrum photographs of the brightest stars. In 1882 they each obtained a photograph of the spectrum of the nebula in *Orion*. Since 1882 many astronomers and observatories have devoted themselves to photographic researches, but little has been published, except by the Observatory of Harvard College. Here the years 1882–1885 were spent in very elaborate experiments, preliminary to undertaking larger and more important researches. The photographic telescope employed is eight inches in aperture. The chief results up to now have been the establishing the relative brightness of one hundred and seventeen stars within one degree of the pole.

A very extensive programme is now being followed at Cambridge by the use of the photographic telescope formerly owned by DR. HENRY DRAPER, supported by a fund provided by his widow, MRS. ANNA PALMER DRAPER. Prisms of glass 12 by 12 inches are placed in front of the object glass and the *spectra* of all the stars in the field of view, down to the 8th magnitude, are simultaneously photographed on the plate. An enormous saving of time is thus effected. The method has many other advantages also, which I need not enumerate here. If some generous citizen of California will provide such a prism for the 36-inch telescope (and such a prism is possible) the spectra of very faint stars can be photographed. If a planet exterior to *Neptune* exists, this is the quickest and surest way to discover it.

In 1882 Dr. GILL, at the Cape of Good Hope, succeeded in photographing the great comet of that year, and in doing this he proved the practicable possibility of making star maps, which should contain all the stars down to the tenth magnitude. In 1885 the Royal Society granted £300 to the Cape of Good Hope Observatory for photographic purposes. Doctor GILL has set himself to the solution of two problems. First, that of securing as soon as possible a com-

plete photographic map of the southern heavens, containing every star visible down to the tenth magnitude, so as to continue the *Durchmusterung* of ARGELANDER. For the first purpose Mr. GILL makes use of one of DALLMEYER'S rapid rectilinear combinations, composed of two concavo-convex achromatic combinations of six inches aperture. This camera is mounted on an equatorial stand, and is pointed by means of a telescope of forty-five inches focal length and three and one half inches aperture. The exposures are an hour long when the sky is clear. Each plate is six inches square, and covers an area of about thirty-six degrees. Every such area is photographed twice, so as to render it impossible to confound the images of faint stars with minute dust specks. In this way a great portion of the southern sky has already been photographed in duplicate.

The same observatory has recently obtained a much more powerful optical apparatus through the generosity of Mr. JAMES NASMYTH, who has purchased a specially corrected photographic objective of nine inches aperture and nine feet focal length, made by GRUBB, of Dublin. The field of this NASMYTH lens will be much more limited than that of the DALLMEYER apparatus, but it is expected to obtain from it a photograph of all stars to the twelfth or thirteenth magnitude inclusive, within a circle of a radius of one or one and one-half degrees.

Mr. ROBERTS, in England, has erected a reflector of twenty inches aperture, and of one hundred inches focus, for stellar photography alone, and has made considerable progress in the work of charting the northern heavens. The size of the field of Mr. ROBERTS' telescope is two degrees in declination, and one and one-half degrees in right ascension. The time of exposure is fifteen minutes in a clear sky. The companion to the pole-star is just visible in four seconds under the best circumstances. Mr. ROBERTS refers to an important difficulty, which is, that in most photographic plates, there are small specks in the film, many of which look like stars, and which are extremely difficult to distinguish from stars even when they are viewed through a microscope. Dr. GILL, at the Cape of Good Hope, avoids this difficulty by taking two photographs of the same field successively, giving to each an exposure of one hour. At Paris, three exposures of an hour each are made, on the same plate.

Mr. COMMON'S experiments commenced in 1879. At this time, using dry plates with his three-foot reflector, he took successful pictures of the *Pleiades*, with one and one half minute's exposure, showing all the stars to the eighth and ninth magnitude. In 1882, he devoted his time to photographing the Nebula in *Orion*, and has obtained wonderful results.

After making such a splendid success with his three-foot reflector, Mr. COMMON is now making one of five feet in aperture. There is no doubt that a mirror of this aperture can be accurately

figured by the optican. The difficulties in using it, come from unequal flexure of its various parts and from their differing temperatures. Difficulties of this nature have never yet been successfully overcome for reflectors of more than thirty-six inches of aperture, but Mr. COMMON's great mechanical skill, knowledge and experience, encourages the hope that he may succeed in this important undertaking.

In September 1884, Dr. LOHSE used the eleven-inch refractor of the Potsdam Observatory to photograph the star cluster in *Perseus*. An exposure of forty-five minntes was given, and stars as faint as the tenth and eleventh magnitude were registered.

A number of other star clusters have also been photographed by Dr. LOHSE. The Savilian Observatory at Oxford (England), has undertaken to study two constellations (*Lyra* and *Cassiopeia*), by photography on plates one degree square.

The early experiments at the Paris Observatory, 1884, were made with a telescope with an aperture of 16-100 of a metre (6.3 inches), and they were so successful that it was decided to make a large instrument specially for photography, and soon an objective of 34-100 of a metre aperture (13.4 inches), and 3 metres and 43-100ths focal length (134 inches), was made. Parallel to this photographic telescope, one of about the same focus, and of 24-100ths of a metre (9.5 inches) aperture, is placed as a directing telescope. In May, 1885, the new photographic telescope was first brought into use, and a few of the important results that have been reached by it are mentioned below. Stars down to the fifteenth magnitude are photographed with an exposure of one hour, the plates being something more than two degrees square. From one to two thousand stars are shown to each square degree with this exposure, using dry plates. On these plates three separate exposures of an hour each, are given, the instrument being moved between each exposure, so as to change the position of the image on the plate about five seconds of arc each time. The three images of the same star thus form a little triangle. By means of this telescope, a new and very faint nebula has been discovered in the *Pleiades*, which would never have been discovered, if we depended on the eye alone. Admirable photographs of *Saturn* have been taken by direct enlargement of the primary image, through a non-achromatic eye-piece, which gives a magnifying power of eleven times. *Hyperion*, the faintest satellite of *Saturn*, a difficult object in the twenty-six inch telescope, at Washington, has been photographed with an exposure of thirty minutes, and the satellite of *Neptune* can be taken in any part of its orbit, as it is situated at present. With an exposure of one hour the eleventh and fifteenth magnitude stars have an actual diameter of about 1-1,000th of an inch, that is in arc about one and one-half seconds. Stars of the fifth and sixth magni-

tude are about one minute in diameter, with long exposures. With a properly limited exposure, these also are of extremely minute dimensions.

The proper exposure for a first magnitude star, like *Sirius* or *Vega*, is not more than 5-1000 of a second. For a star just visible to the naked eye, half a second is sufficient. For stars of the tenth magnitude, twenty seconds; of the twelfth, two minutes; of the thirteenth, five minutes; of the fourteenth, thirteen minutes; and for the faintest visible, an hour and twenty-three minutes. These results are, of course, a minimum, and also they are but approximate.

As far as is known, the growth of the image of a star upon the photographic plate is equal, and concentric with the point of the plate, on which the center of the star falls.

At the suggestion of the Director of the Paris observatory an International Congress of Astronomers was held in Paris in April, (1887), to decide upon a plan according to which a series of photographic charts of the sky might be made by a large number of observatories co-operating on a single plan. The conference was composed of many celebrated astronomers and they decided to approve of the plan proposed by Admiral MOUCHEZ. The observatories of Paris, Algiers Toulouse, Bordeaux, Melbourne, Sydney, Rio Janeiro, La Plata, Santiago de Chili, San Fernando, and Mexico have already agreed to join in the work, and those of Vienna, Oxford, etc., may also assist.

The resolutions of the Congress may be summarized as follows:

I. A photographic chart of the heavens containing all stars down to the fourteenth magnitude is to be at once undertaken, the plates to be in duplicate.

II. A second series of photographs with shorter exposure to include stars of the eleventh magnitude, is to be made concurrently with the first for the purpose of forming a catalogue, and to determine fundamental positions in the first series.

III. All the photographic plates are to be prepared from the same formula.

IV. All the photographic telescopes are to be like that now at the Paris observatory.

There are 41,000 square degrees in the whole heavens, and if six square degrees can be registered on a plate (with one hour's exposure), 7,000 such plates must be made, requiring at least 7,000 hours. To avoid mistakes, *at least* two exposures must be given for each region, or 14,000 plates and 14,000 hours are absolutely necessary.

If we allow one hundred clear nights in a year (which is a fair allowance for all observatories, except the Lick observatory, where we can count on at least two hundred), it would require one hundred and forty years at any one observatory to do this work, or fourteen at ten observatories taking one plate per night.

Although it seems presumptuous to differ from the conclusions of a congress of astronomers so eminent as those who formed the Paris conference yet I personally have grave doubts whether the strict adherence to a plan, which is indispensable to success, can be maintained at so many different establishments for a period of even five years, within which time the congress hopes to complete the work. Photographic processes are now changing with wonderful rapidity and the methods of even two years ago are to-day practically obsolete.

The whole subject still seems to me to be in too unsettled a state to warrant an international undertaking of such magnitude, at present. A number of years must perhaps be spent in tentative researches before the rght paths are struck out. I give some of the most obvious directions for these trials in what follows.

The two hundred and sixty or more small planets (asteroids) which lie between *Mars* and *Jupiter* have all been discovered by the slow process of comparing a star map, night after night, with the heavens. A star not on the map is either an omitted star to be inserted, or a minor planet, known or unknown. A photographic objective of twelve inches aperture will show a *trail* for a star of the magnitude of the brighter asteroids with an exposure of half an hour. An hour's exposure will probably show the trail of the faintest asteroids (12-13 magnitude). One of the immediate results of the application of photography will undoubtedly be to greatly increase the number of known asteroids.

There are reasons to believe in the existence of a major planet exterior to *Neptune*. If such a planet exists, it is not likely to be brighter than the tenth magnitude, and its motion will be very slow. Hence it is unlikely, at least, that such a planet can be discovered by its trail on the plate. The method of three exposures on the same plate employed at Paris probably might not disclose the existence of a trans-Neptunian planet, though it would suffice for the detection of *Neptune* itself in most parts of its orbit. Probably the surest way to detect such a body, if it exists, would be to take photographs of the same region on successive days. Such plates would then have to be laboriously compared, star by star. Doubtful cases would require a third night's work to be done in order to decide. A blue-print of two such plates will enable all the brighter stars to be quickly compared and disposed of. The real labor will then be confined to the stars less bright than the faintest which can be blue-printed.

The problem of the constitution of the stellar universe must be studied, it seems, by some kind of celestial statistics derived from counts or *gauges* of the stars. Nearly all the conclusions we have so far reached, are based on the counts made by Sir William Herschel. I have myself spent much time in continuing these. All such work is now useless. Photographic maps will give

us all the requisite data, and will throw much light, too, on another closely connected problem—the extinction of light in space—provided only that all negatives taken from this object are made strictly comparable in every respect. This *proviso* is of the utmost importance, and is very difficult to be lived up to in any work done by co-operating observatories. It is just possible that photometric measures of the photographs of a very eccentric asteroid can now be made with sufficient delicacy to settle the question whether light is, or is not, extinguished in space.

The precision of the photographic images of stars is so great that there is no doubt that measures of the negatives of double stars, of star clusters and groups, will, at least in most instances, take the place of the painful and laborious micrometric measures which are now employed by observers. The photographs have their own errors, and many of them; but these are all susceptible of investigation.

The shrinkage of the gelatine films of the negatives is likely to prove a grave difficulty in the application of photography to exact astronomy, but this can always be detected by photographing a net work of lines on glass. Very serious difficulties of this kind have lately been met with by Professor PRITCHARD, of Oxford, in his researches on the (photographic) parallax of 61 *Cygni.*

But photographic plates have also many capital advantages. For example, the photographic impress of a star gives really its *mean* or average position, freed from those accidental and transitory variations of place which are due to variations of atmospheric refraction —a constant source of error. The saving of time is also important. An exposure of an hour has given (at the Paris observatory) a map of 5,000 stars in four square degrees in the constellation *Cygnus.* The best maps we now have give 170 of the brightest stars only, in this place. To map 5,000 stars by the eye alone would require several years. The writer spent all the time he could spare from routine observations during four years with the twenty-six inch equatorial, at Washington, in a study of the Nebula of *Orion.* Every important result reached by that study, and very many not comprised in it, was attained by Mr. COMMON's photograph, (subsequently taken), which required an exposure of forty minutes only.

Another important advantage of the new methods is that they do not require highly skilled observers. It required a BESSEL or a STRUVE to determine the parallax of 61 *Cygni* or of *Vega.* But photographic exposures can be made, and glass negatives successfully measured by well trained assistants, after the plan of observation has once been thoroughly thought out. This is no slight benefit. The skill of the astronomer is reserved for real difficulties, and the merely laborious work can be done in duplicate, if necessary, by younger men.

Again, the chemical plate is sensitive to a whole series of rays, which produce no effect on the human eye. Only half of the faintest stars of any photographic map, are visible to the eye in the same telescope. Photographic methods thus increase the range of our vision immensely; they also increase its sharpness. The photographic plate will register the sum of all the impressions it receives. It does not tire, as the eye does, and refuse to pay attention for more than a small fraction of a second, but it will faithfully record every ray of light that falls upon it, even for hours, and finally it will produce its automatic register, so that the eye can see it, and so that this can be measured, if necessary, again and again. The permanence of the records is of the greatest importance, and so far as we know it is complete, when the best modern plates are employed. We can hand down to our successors a picture of the sky, locked in a box. What would we not give for such a record bequeathed to us by HIPPARCHUS or by GALILEO!

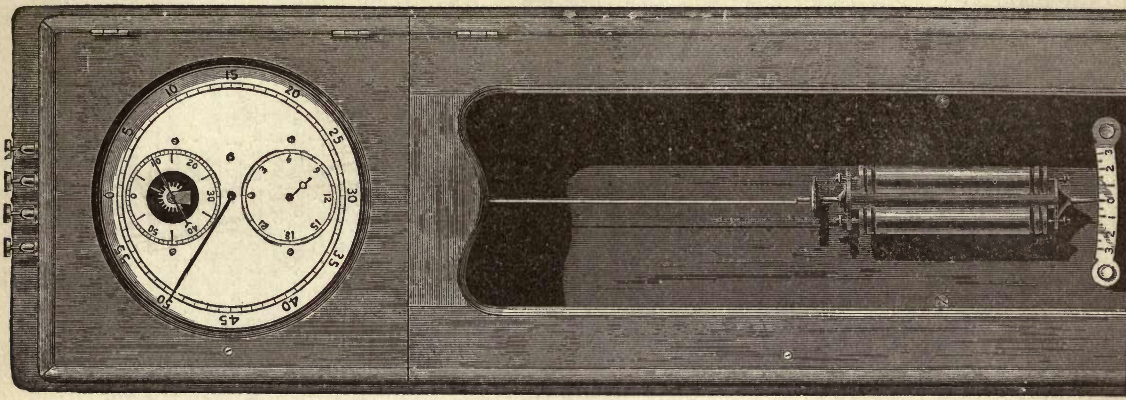
It will be of interest to briefly state how far the equipment of the Lick observatory will fit it to engage in this important branch of research. It is known that the situation of the observatory is the finest in the world, both as to the number of clear days, and as to the quality of steady atmosphere. The observatory will be completely equipped for all micrometric work, and also for all spectroscopic researches. We may summarize its facilities for excursions in the fields of astronomical photography as follows: We have a photographic objective 33-inches in aperture, which is six times more powerful than any objective now made; the largest Paris glass is 13 inches in aperture. This is mounted in the most perfect manner, and we can employ the 12-inch Clark telescope, now in the north dome, as a pointing telescope for the large objective. The 12-inch telescope will be mounted alongside the other. An electrically controlled driving clock will keep the two telescopes accurately directed during the exposure. Our objective will collect six times the light of any other photographic telescope now made. We should therefore be able to photograph fainter objects. The focal length of the photographic combination will be about 550 inches, and 1″ on the plate will therefore be about 0.003 inches. This is a quantity whose $\frac{1}{100}$ part can be measured.

A single exposure will give us a map of the sky comprising four square degrees on a plate 22x22 inches. A few minutes will impress on this plate a permanent record of the position and brightness of all the stars visible in even the largest telescopes. A comparison of two such plates taken on different nights will point out any changes which might easily escape the most minute observation by other methods. The sun's image unmagnified will be five inches in diameter; a large sunspot will be the size of one's finger

nail. Beautiful photographs of the planets can be taken so as to register with perfect accuracy the features of their surfaces. Comets and nebulæ can be studied at leisure from their automatic registers as one studies a copper-plate engraving. The variations of refraction from the horizon to the zenith can be made to record themselves for measurement. There is absolutely no end to the problems lying close at hand, and their number and their importance will develop with time. We are merely at the threshold of this subject. There is no question but that the large telescope with its two objectives in its absolutely perfect site is the most important astronomical instrument in the world. Mr. LICK's desire has been fulfilled so far, and more than fulfilled. But a mere instrument is nothing but a splendid monument (to more than one man) without intelligent use. Californians must not point at this telescope and say that it is the largest in the world, but it must also be their effort to make it the most useful.

Although the whole plan of the observatory has been made with direct reference to keeping its running expenses low, it is clear that the work of our observers must be concentrated on the large equatorial, and even then that their energies will not be sufficient to utilize every moment. It is not our intention to jealously guard the immense scientific opportunity for ourselves, for California, or even for the United States. The real gift of Mr. LICK was to the world. We mean to put the large telescope at the disposition of the world, by inviting its most distinguished astronomers to visit us, one at a time, and to give them the use of the instrument during certain specified hours of the twenty-four. Each day there will be certain hours set apart when the observatory staff will relinquish the use of the equatorial to distinguished specialists who will come upon our invitation from the United States and from Europe, to solve or to attack some one of the many unsolved problems of astronomy. In this way we hope to make the gift of Mr. LICK one which is truly a gift to science, and not merely a gift to California and to its University.

Even under such circumstances it will be impossible to utilize the instrumental outfit to the full. It was clearly the duty of the Lick Trustees to make this observatory perfect in every respect, and to provide it with all the instruments necessary to a complete equipment. This they have done as economically and wisely as they could. The instruments are all necessary, and they are mounted in the most perfect manner. Each one is directly subordinate to the large equatorial and accessory to it. Nothing has been purchased, and no work has been done, which does not directly tend to make the observations made by the large equatorial either more complete, or more immediately useful. The cost of the whole observatory may fairly be said to be the cost of the great telescope in place, and entirely ready for work.



STANDARD MEAN-TIME CLOCK
Signals are sent every noon from this clock to every railway station in California, etc., as far East as Ogden and El Paso, and as far North as Portland.

XI.—CLOCKS AND TIME-KEEPING.

It is not so very long since the regulation of time in the United States, and indeed all over the world, was considered a very minor matter. I have been informed by a naval officer now living, that when he was on duty at the Norfolk Navy Yard, the only time-piece depended upon to regulate the hours of hundreds of Government workmen was a sun-dial situated in the grounds. As is well known, a sun-dial gives apparent solar time, which is sometimes fifteen minutes fast of mean time—the time ordinarily used—and sometimes sixteen minutes slow. This variation of half an hour apparently made no difference to the officers of a government service only a few years ago. The introduction of railways, the growth of large cities and the increasing value of the moments of men of business, have created quite another state of things. The public has been educated by these means; but perhaps more rapidly and effectively by the use of the telegraph between cities separated by many degrees of longitude. A telegram from the House of Commons, in London, at one o'clock in the morning, reaches San Francisco in time to be printed in the later editions of the evening papers of the day before. Railway travelling, which is so common in America, where distances are large and the public highly intelligent, has also familiarized us with the fact that there are different standards of time and that these change from place to place. In November, 1884, all the railway times of the United States were suddenly changed from their old local values to one set of uniform standard values, and this was done without any apparent friction or annoyance; yet the interests of thousands of citizens were directly affected. I believe there is no other country in the world which could take such a step with such complete intelligence on the part of its citizens. Up to 1884 each railroad had a standard of time of its own. For instance, the Pennsylvania Railway was run on Harrisburg time between Philadelphia and Harrisburg, and at that place a sudden change was made and the rest of the journey to Pittsburgh was accomplished on Pittsburgh time. Similarly the New York Central was run on Poughkeepsie and Rochester time in its different divisions, and so with other railways. This at last grew to be an intolerable nuisance, and in searching for the remedy the Railway Convention, which met in 1883 in Chicago, settled on a very philosophic and simple plan. It has its disadvantages, of which we need not speak here, since the system has already become firmly rooted and since its advantages are many and obvious.

Standard time, as it is understood in the United States, is a time of which the minutes and seconds are exactly the same as those of a standard mean time clock at the Royal Observatory, Greenwich, England. The hour only is different. *Inter-colonial time* serves for the British Provinces about New Brunswick and for the extreme East of the United States; it is four hours slower than Greenwich time. *Eastern time* is exactly five hours slower than Greenwich time and corresponds nearly to the local time of Philadelphia. *Central time* is six hours slower than Greenwich time and corresponds nearly to the meridian of St. Louis and New Orleans. *Mountain time* is seven hours slower than Greenwich time and corresponds roughly with the local time of the meridian of Denver, while *Pacific time* is eight hours slower than Greenwich time and corresponds approximately to the local time of Sacramento. As we on this Coast are more particularly interested in Pacific time, I give the exact figures: The local time of the astronomical station of the Coast Survey in the Plaza in San Francisco is 8 hours, 9 minutes, 38.35 seconds slower than Greenwich time. The local time of Mount Hamilton (Lick Observatory) is 8 hours, 6 minutes, 34.3 seconds slower than Greenwich time. So that Mount Hamilton local time is 3 minutes, 4 seconds faster than San Francisco time. All the railways in California run on Pacific time, therefore this time is 9 minutes, 38.4 seconds faster than San Francisco time and 6 minutes, 34.3 seconds faster than Lick Observatory mean time.

When an observation is taken at Mount Hamilton it determines the exact local time of the meridian of the instrument with which the time was observed. The standard clock is not kept, however, to this local time, but it is regulated so as to be 6 minutes, 34.3 seconds faster than this. That is, it is set to Pacific standard time and kept at this point.

The work of astronomers is usually very far removed from what is called practical utility. The American public is highly interested in all scientific results which can be stated in popular form, including those in astronomy, but there is almost only one point where the work of astronomical observatories touches the business interests of communities directly. This point is in the distribution of time by electric signals from an observatory to railroad and telegraph companies, to city and tower clocks, to private business firms and to manufacturing and other corporations, for commercial purposes. Nearly every observatory of importance takes great pains to see that the cities and individuals in its vicinity are fully supplied with correct time. The advantages of these observatory time-services are manifold and scarcely need be pointed out. A high degree of accuracy and uniformity is secured by them, and an immense amount of petty vexation is spared. Anyone who has looked at the public clocks of San Francisco, which often vary five to six minutes between themselves, and especially anyone who has lost an ap-

pointment through this variation, can appreciate this point. In all sea-ports the chronometers of merchant vessels can be well regulated and rated by the dropping of a time ball by an observatory; and this is a valuable indirect aid to navigation. A less obvious but not less important consideration is the connection thus formed between the more abstruse work of the observatory and the ordinary affairs of every day life, which brings continually before the public mind the practical application of astronomical science and inspires it with confidence in the precision of scientific methods. The increased punctuality which is insured by the knowledge of the correct time is a positive moral benefit to the community. Punctuality is one of the minor mechanical virtues, but it is no less a virtue. It has been said that punctuality is the politeness of kings; if so, it is positively obligatory upon us common people.

THE LICK OBSERVATORY TIME SERVICE.

One of the first works undertaken at the Lick Observatory was to fit it to be the center of a system of time distribution for the surrounding country, and to provide the railways radiating from San Francisco with time signals which should traverse the immense distances separating California from the observatories of the Eastern States. In the early part of 1886 I made an arrangement for supplying the time signals automatically from the clocks of the Lick Observatory to the Southern Pacific and other railway companies, as well as to jewellers in San José. These arrangements were authorized by the Lick trustees, who had a full sense of their duty to the community to provide such service. I have thought that it might be interesting to give a popular account of exactly how this work is done, in order that the public at large may have confidence in the service and that they may appreciate the amount of trouble that is taken to see that the time signals are correct. In order to send out these signals from the observatory, a special clock was constructed by HOWARD & Co., of Boston, fitted with an electric apparatus for making signals over any telegraph line. This clock is kept to standard time by means of observations with the transit instrument. The time kept by the clock is mean solar time and the clock can be regulated by observations of the sun; but as the sun only crosses the meridian once a day and therefore can only be observed once, it is found more convenient in practice to observe stars, of which many are available whose positions are as accurately known as that of the sun. The theory of determining the time by transit observations is very simple. The transit instrument is placed exactly in the meridian—that is, so that when it is revolved it will describe a North and South line in the sky. At the instant that a star of known position is crossing the meridian on its way from rising toward setting, the exact moment by the clock at which the star crosses a spider line stretched across the eye-piece of the

transit instrument is noted. Knowing the position of the star, we know by a calculation exactly the time at which the star *ought* to be on this thread. Looking at the clock we observe the minute, second and tenth of a second by the clock at which it actually *is* on the middle wire. The difference between these two quantities gives us the correction of the clock as derived from the observation of this particular star. Several stars are observed on each night in order to get from their average a more correct determination than could be obtained from any one, and in order to correct for any slight deviations in the position of the transit instrument itself with respect to the meridian. In this way on each night of observation the error of the clock is determined accurately within two or three hundredths of a second of time. Such observations as have been described are made every two or three nights upon a set of four or more stars. The clocks we use can be trusted to run accurately enough in the interval between observations to insure that the error of the time signals shall be at no time greater than two or three tenths of a second, but for greater security the standard clock is daily compared with each one of four other astronomical clocks and with two chronometers, so that even if the weather should be cloudy, we could depend upon the average running of these time-pieces for a much longer period than two or three days. To give an idea of the accuracy of running of these clocks I quote from the observatory register of 1887. It should be understood that these finer clocks are allowed to run as they will, and that their errors are allowed for by a calculation, instead of meddling with the hands and correcting their indications by small quantities. This clock, which was made by Dent in England and cost $550, is of the finest possible construction. Watchmakers will understand this when I say that the pinions have eighteen leaves. On the 1st of March, 1887, it was .08 of a second fast; on the 4th it was .06 of a second fast; on the 6th it was .08 of a second fast; on the 8th it was .13 of a second fast, and so on until the 7th of April, when it was .02 of a second fast. That is, between March 1st and April 7th its total variation was .06 of a second. The other clocks of the observatory are practically as good as this. It will be evident, as the time at the observatory is known from each night's observations to about .03 of a second, that it can be well kept between the observations by means of admirable clocks like these.

HOW THE TIME IS SENT OUT FROM THE OBSERVATORY.

The next question is: How do we transmit the time from the observatory to the railway station in San José? This is done automatically by one of the clocks itself. This particular clock is not allowed to accumulate any error, but it always kept exactly right. At 9 o'clock in the morning of each day it is compared with the other clocks and its error determined; and if any exists, this is

corrected by placing small weights upon the pendulum, so that in a short time—less than an hour usually—the clock indicates exact Pacific time. Inside of this clock there is a simple arrangement by which an electric current is interrupted every two seconds of the clock. This electric signal is sent over our own telegraph line to the Southern Pacific railroad station at San José and received on the telegraph instrument there, precisely as if the beats made by the clock automatically had been made by a telegraph operator at Mount Hamilton. In order to distinguish the end of each minute one of these beats is always omitted, namely that one which corresponds to the 58th second of each minute. That is, if you were listening to the signals in the railway station you would hear the clock beat 0 seconds, 2 seconds, 4 seconds, 6, 8, 10 etc., and finally 52, 54, 56, *not* 58 and then 60. So that if you knew that your watch was not more than half a minute wrong, you would stand before the telegraph instrument at San José with your watch in your hand and listen for a pause longer than usual in the beats which were being repeated from our clock. When this long pause occurred, you would observe the second hand of your watch; and the first dot that came on the telegraph instrument after the long pause would mark the beginning of a minute. But you may not always know the error of your watch so closely as this, and the clock is arranged to automatically leave out the 52nd, 54th, 56th and 58th beats of *every fifth minute*; that is, of course, every minute whose number ends with 0 or 5. Suppose, for example, that you knew that your watch was within two minutes of correct time about three or four minutes before 10 o'clock in the morning. In order to know exactly its error, you would have to stand again before the telegraph instrument and listen to the beats of the Mount Hamilton clock as they are repeated until you heard a pause in the beats which was longer than usual, a pause, indeed, as long as ten seconds — from fifty seconds to sixty seconds. You know that that pause is at the end of the minute immediately preceding 10 o'clock, and the first dot after this long pause, will mark the beginning of the hour. The method is much simpler in practise than it appears to be from the description and a child can use it.

At this telegraphic instrument in San José, methods are provided for repeating the beats of our clock over four different circuits. One of these circuits extends over the Southern Pacific line east of the bay to the Oakland mole, and every day at 12 o'clock the beats of the Mount Hamilton clock are transmitted from San José over this line to the Oakland mole. At this point they are received on a ticker at one end of the table. At the other end of the table sits an operator with his hand on a telegraphic key, and he beats on this key in exact coincidence with the Mount Hamilton clock signals, which are thus sent over all the lines of the Southern Pacific Company as far east as Ogden, as far south as El Paso, and as far north as Portland.

Another pair of points at San José leads to the telephone office of the Sunset Telephone Company, and they can, at will, allow a ticker to beat in their local office. If desired, this ticker can be heard in San Francisco in any telephone. The owner of the telephone has simply to call the central office and to ask that the Mount Hamilton clock be placed in connection with his telephone. The operator will do this promptly and the beats of the clock can be readily heard, and anyone's watch can be set in San Francisco without difficulty from the audible beats of a clock 60 miles distant.

A Circular of the Telephone Company is reprinted here.

SUNSET TELEPHONE-TELEGRAPH CO.

LICK OBSERVATORY TIME-SIGNAL.

Pacific Standard Time.

Post this Notice near your Telephone.

To hear the beats of the Lick Observatory Standard Clock, call the Central Office and ask that the San José Operator put on the Lick Observatory Clock Signal. When this is done the beats of the Lick Observatory Clock will be heard every two seconds. At the end of every minute the 58th second is omitted. At the end of every 5th minute (0, 5, 10, 15, 20, 25, 30, 35, 40, 45, 50, 55, 60) the 52d, 54th, 56th and 58th seconds are omitted.

TO SET YOUR WATCH RIGHT

Get the beats of the Lick Observatory Clock in your telephone and hold your watch where you can see the second hand; listen to the beats which are heard every two seconds, until a pause of more than two seconds comes; the first dot after such a pause begins some minute. If the pause is ten seconds long, the minute is one of the numbered minutes of your watch-dial.

Another pair of points at San José to the jeweler shop of Mr. Allison, a leading jeweler, who is establishing a local service of controlled clocks. Also, still another pair of points was intended for use on the South Pacific Coast Railway; but as this has become a portion of the Southern Pacific system, these are not used at present.

In this simple way the standard time determined by observation at Mount Hamilton, is distributed to the railways and used by them at every telegraph station between San Francisco and Ogden, El Paso and Portland, Oregon. Besides this, every telephone subscriber in San Francisco can use our time by simply calling the central office to give it to him.

The standard time is regularly determined at the private observatory of Professor Davidson in San Francisco. At the United

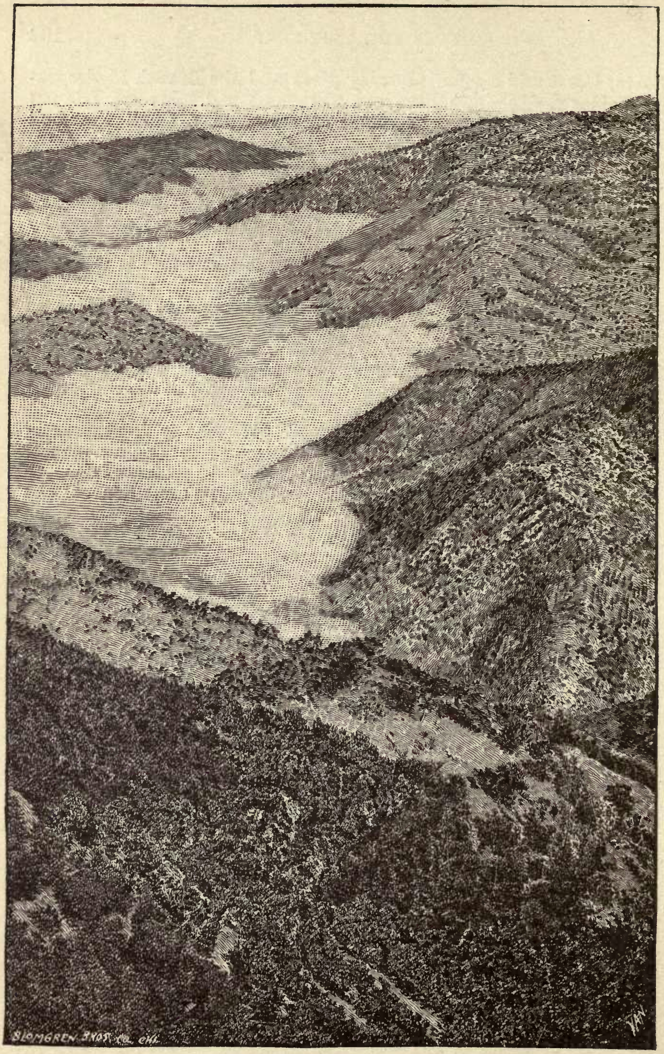
States Coast and Geodetic Survey office and the Branch Hydrographic office the accurate time can always be had. Messrs. LARSEN and WILSON, 201 Kearny street, have dropped a small time-ball daily at noon for the past ten years. Several of the chronometer makers in the city also determine their own time by observations of the sun with small instruments. For the sake of uniformity it would be better if they took their time from the Lick observatory signals or from those which are daily set at noon by the observatory at the Mare Island Navy Yard. This latter observatory is under the charge of a competent lieutenant in the navy who makes the necessary observations and sends the signals which drop the time-ball on Telegraph Hill and regulate the clock in the Merchants' Exchange.

At the Chabot observatory in Oakland, Mr. BURCKHALTER (who is in charge) regularly determines the time; and during the college year the same is done at the Students' Observatory of the University of California, by Professor SOULE.

At any one of the places named some time-piece is kept running nearly to standard time, and a comparison with this time-piece, (after allowing for its small error) will enable one to set his watch exactly to time. Any telephone subscriber can at any hour of the day call the Central office, and ask that the Mount Hamilton clock be allowed to beat for 5 minutes on his circuit. The beats of the clock can also be heard at the conversation-room of the Sunset Telephone Company, in the operating-room of the Western Union Telegraph Company (at noon only) and (also at noon) on a sounder at the shop of Mr. MCCONNELL, 618 Market street. The time-ball on Telegraph Hill is dropped with accuracy and can be used by all who can see it.

It will be seen that we have unusual facilities for obtaining accurate time. A very little observation of our public clocks will show that some of them are not regulated with sufficient care. Every public clock is, or ought to be, under the care of some jeweler, and it should be his pride as well as his duty to keep the hands of its various dials indicating the same time, and to have the time shown by its hands and by its bells, (if it strikes) exactly and precisely right.

I trust that I have made it plain that there is a real value to the whole community in accurate time-keeping, and that the Lick Observatory is already doing its best to care for the public interest in this regard. Every railway train west of the Rocky Mountains runs more safely for the observations which are nightly made at Mount Hamilton, and every ship-master who will take the trouble, can make a better land-fall at the end of a long voyage because the observatory has fine instruments, good clocks and competent and faithful observers.



FOG IN THE MOUNTAIN RANGE

XII. THE PRINCIPAL OBSERVATORIES OF THE WORLD.

It may fairly be assumed that the reader of this hand-book will wish to know something, at least, of the other principal observatories of the world, if for no other reason than to intelligently compare their equipment and conditions with those of the Lick Observatory.

For this reason I have collected in this place brief notices of the instrumental outfit, the *personnel*, etc., of the chief observatories now in existence, and give them in this chapter.

I have made free use of the capital article on observatories written by my friend Dr. DREYER, director of the Armagh Observatory, for the last edition of the *Encyclopædia Britannica*, and I take pleasure in referring those who wish more extended information to his original article. It is worthy of notice that the establishment of the Lick Observatory on a high mountain has influenced the selection of the sites of several of the later established observatories. I have naturally given a fuller account of American, and especially of Californian, institutions than of others. It not infrequently happens that in our search for information we neglect the most obvious sources. It is also especially important to Americans to realize the vast instrumental equipment of American observatories; to inquire why so many of them are comparatively idle; and to reflect that a few thousand dollars judiciously expended in an endowment fund for the payment of skilled observers to use the instruments already provided, will be of more service to astronomy, and redound more to the credit of the giver, than ten times the sum spent in establishing one more of the expensive observatories in which no observations are made, of which we already have too many.

It is not too much to say that astronomy would not suffer if no *new* observatory were to be founded in the United States for the next half century, provided that a few generous and far-seeing men would furnish the means to keep our present establishments fully active. The Lick Observatory itself could easily keep twice its present staff of observers and computers at work. A glance over the list of German observatories here printed will show with what slender instrumental equipment the greatest works have been accomplished. Co-operation is also a golden word. With this preface, which will seem the more essential the more one is familiar with the facts, I proceed to give the list of the chief observatories of the world, arranging them by countries.

GREAT BRITAIN AND IRELAND.

Royal Observatory of Greenwich: Founded in 1675 for the promotion of astronomy and especially of navigation. The chief observations therefore have always been devoted to the accurate determination of the places of the moon and of the fundamental stars. Since 1873 daily photographs of the sun and spectroscopic observations of sun and stars have been made. The director is called the astronomer-royal: and the astronomers-royal have been some of the most noted men of England, namely FLAMSTEED, HALLEY, BRADLEY, MASKELYNE, POND, and Sir GEORGE AIRY (1835—1881). The present astronomer-royal is W. H. M. CHRISTIE, who succeeded Sir GEORGE AIRY in 1881. At present the staff consists of the director, nine astronomers and a large number of computers. The annual expenses of the observatory are about $42,000. The principal instruments are the LASSELL reflecting telescope of 24 inches aperture; a refractor by MERZ of 12.8 inches aperture; a meridian-circle of 8 inches aperture; an alt-azimuth of 4 inches aperture; with photographic, meteorological and other instruments in great variety. A daily time-signal is sent all over England, and time-balls are dropped at various sea-ports. A meteorological and magnetic observatory has been maintained since 1838.

The observations since 1836 have been published annually, with commendable promptness, in large quarto volumes and freely distributed to other observatories and to men of science. It is truer now than when DELAMBRE said it half a century ago, that if the whole work of all observatories save that of Greenwich alone were irrevocably lost, the entire science of astronomy could be recovered from the Greenwich observations.

Oxford; the Radcliffe Observatory: It was founded in 1771. Since 1839 observations have been regularly made and published in octavo by the Radcliffe observer and his assistants. (There are now 3 assistants employed.) The instruments are mostly small, but they have been used with great advantage to astronomy by the able observers who have presided over this establishment—namely JOHNSON, MAIN and STONE.

Oxford University Observatory: was founded in 1875; the Savilian Professor, Dr. PRITCHARD, is the director, who is aided by two assistants. The chief instruments are a 12¼-inch refractor by GRUBB and a 13-inch reflector made and presented by WARREN DE LA RUE. Celestial photometry and photography are especially attended to. The observations are regularly published in quarto.

Cambridge University Observatory: This observatory was founded in 1820 and under its noted directors, AIRY, CHALLIS and ADAMS has done most valuable work. The chief instruments are a CAUCHOIX refractor of 11½-inch aperture and a fine meridian circle by SIMMS (8 inches). There are two or more assistants. The observations (1828—1865) are printed in 21 quarto volumes.

Liverpool (Birkenhead) Observatory: Founded in 1838 and chiefly devoted to a time service for Liverpool, and to the investigation of the rates of ships' chronometers.

Kew Observatory: Established in 1842. This is the central meteorological observatory of Great Britain. Daily photographs of the sun were taken from 1863 to 1872.

Royal Observatory of Edinburg: Founded in 1811. The Royal Astronomer for Scotland is director and at present he has two assistants. T. HENDERSON (Director from 1833 to 1845) made and published a most valuable and accurate series of observations of star positions. Observations of subterranean temperature have been carried on since 1837, and the present Royal Astronomer (C. PIAZZI-SMYTH) was the first to demonstrate the advantages of mountain sites for astronomical observatories, by his expedition to Teneriffe, (during 1856). His spectroscopic observations are also well known, as well as his researches on the Great Pyramid.

Glasgow Observatory: Founded in 1840. The chief instrument is a meridian circle, with which the present Director (R. GRANT) has observed an admirable catalogue of 6,415 stars.

Dublin Observatory: (at Dunsink); founded 1785. The principal instruments are an $11\frac{3}{4}$ inch CAUCHOIX refractor and a 6.4 inch PISTOR & MARTINS' meridian circle. Both these instruments have been energetically employed by BRUENNOW and by his successor, the present Director (Sir R. S. BALL) in determinations of stellar parallax, etc. The observations are regularly published in quarto.

Armagh Observatory: Founded in 1791, enlarged in 1827. Very important star catalogues have been published from observations made by Dr. T. R. ROBINSON (1823–1882). Dr. J. L. E. DREYER is now Director.

Mr. A. A. Common's private observatory, Ealing, is noted for the work done with the 36-inch reflector (1879–1885) and especially for admirable celestial photographs. Mr. COMMON is now building a 60-inch reflector.

Earl Crawford's private observatory at Dun Echt, Scotland, is one of the best equipped of modern observatories, and has made itself a name by solid work in various fields. The chief instruments are a 15-inch refractor, by GRUBB, a fine meridian circle, etc., with spectroscopes, etc. The observations are printed in quarto form.

Mr. R. S. Newall's private observatory at Gateshead has possessed a 25-inch refractor by COOKE since 1870. The instrument is very fine in every respect, but it has remained idle, so far as science is concerned, all these years.

Lord Rosse's observatory at Birr Castle. In 1839 a 3-foot reflector, in 1845 the famous 6-foot reflector, were made and mounted by the father of the present Earl. Much interesting work has been done here in various fields.

Many other private observatories might be mentioned here which well deserve a place, but they are omitted for want of room.

FRANCE.

National Observatory of Paris: Founded in 1667. The CASSINIS, BOUVARD, ARAGO, LE VERRIER and DELAUNAY have been directors. The present director (Admiral MOUCHEZ) aided by a most efficient staff, has infused a new life into practical astronomy in France and has again placed this great establishment in a foremost position. The principal instruments are a 29-inch, a 15-inch, a 12-inch, two 9½-inch refractors, two meridian circles and very many minor instruments. Besides these, photographic refractors of various sizes (the largest 13 inches in aperture) have been lately used with splendid results by the brothers PAUL and PROSPER HENRY. There are many astronomers, assistants, etc. The work is regularly published in quarto volumes (about 60 of which have been printed). The University observatories of Lyons, Bordeaux and Toulouse are allied with the National observatory and are well equipped.

Meudon Observatory: Founded in 1875 by JULES JANSSEN the present Director. This observatory is devoted to spectroscopic observations and especially to solar photography. There are several assistants.

Marseilles Observatory: Founded 1749; rebuilt 1869. The principal instruments are a 9½-inch refractor and a 32-inch reflector. The director (E. STEPHAN) has several assistants.

Nice Observatory: Founded in 1880 by M. BISCHOFFSHEIM, the banker, and presented to the Bureau of Longitude. It is on Mont-Gros, near Nice. It has a 30-inch refractor by the HENRY brothers, a fine meridian circle of 8 inches aperture and many other instruments of the finest kind. The director is M. PERROTIN and there are several assistants.

GERMANY.

The principal observatories of Germany are connected with the great Universities or with Academies of Science. They have in general been distinguished not by great instruments but by great men.

Royal Observatory of Berlin: Founded in 1705, rebuilt in 1835. The principal instruments are a 9½-inch FRAUENHOFER refractor (with which the planet *Neptune* was first seen in 1846) and two PISTOR & MARTINS' meridian circles of 4 and 7 inches aperture respectively. All the instruments have been actively employed. The observations are regularly printed.

Observatory of Bonn: Founded in 1841. A refractor of 6 inches and meridian circles of 4½ and 6½ inches aperture are the chief instruments. Here the *Durchmusterungen* of the sky (catalogues of *every star* from the first to the tenth magnitude) have been made by

ARGELANDER, KRUEGER and SCHOENFELD. The positions of more than 500,000 stars have been determined at this observatory. The results are printed in 8 quarto volumes. The present director is Professor SCHOENFELD who has several assistants.

Strassburg Observatory: completed in 1881, contains an 18-inch refactor by MERZ, a 6½-inch REPSOLD meridian circle, alt-azimuth etc., etc. The observatory is built in the best manner and is intended to be perfect in all respects. There are several astronomers attached to it. The present director is W. KOBOLD.

Royal Observatory of Munich: Founded in 1809. The principal instruments are an 11-inch refractor and a meridian circle. The director (Professor SEELIGER) has several assistants. The observations are regularly published in octavo.

Royal Observatory at Potsdam: This observatory is devoted to astrophysical researches. The chief instruments are two refractors of 11½ and of 8 inches aperture made by SCHROEDER and GRUBB, respectively, besides photometers, spectroscopes, etc. The observatories of Potsdam and of Lund, working jointly, have recorded the spectra of each one of the principal fixed stars. The results are printed in quarto volumes.

Observatory of Leipzig: Founded 1787—90, rebuilt 1861. Its principal instruments are an 8½-inch STEINHEIL refractor and a 6.3-inch PISTOR & MARTINS' meridian circle. It has long been noted for the important work done by the various astronomers who have been attached to it during the past 50 years. The present director is Professor BRUNS.

The observatories of Bothkamp, Dresden, Gotha, Gottingen, Hamburg, Kiel, Koenigsberg, Karlsruhe, etc. would all deserve mention in a more extended notice.

AUSTRO-HUNGARY.

Imperial Observatory of Vienna: Founded 1756, rebuilt 1826, again rebuilt in a new site 1879. The principal instruments are a 27-inch refractor by GRUBB, a 12-inch by ALVAN CLARK, meridian circles, etc. The director (Professor E. WEISS) is aided by a corps of assistants, one of whom, Dr. J. PALISA, has discovered more than 60 mincr planets. The observations have been regularly published since 1821.

Private Observatory of DE KONKOLY at O'Gyalla, Hungary: Established in 1871 and specially devcted to spectroscopy, photography etc. The principal instrument is a 10-inch Merz refractor. The results are published in quarto volumes. The observatories of Pola, Kalocza, Héreny etc., should be named among the more important establishments of Austro-Hungary.

SWITZERLAND.

Observatory of Geneva: Founded in 1773, rebuilt in 1830. A 10-inch refractor is the principal instrument. The observatories of

Zürich, Berne, and Neuchâtel are important. Especial attention is devoted in all Swiss observatories, to providing accurate time signals to watch-manufactories.

SPAIN AND PORTUGAL.

The observatories of Madrid, Cadiz, Lisbon and Coimbra are among the more important. They possess some excellent instruments; but comparatively very few observations come from these establishments.

ITALY.

Observatory of Milan: Founded in 1763. In 1875 an 8-inch MERZ refractor was mounted and in 1885 an 18-inch by the same artist. The director (Professor SCHIAPARELLI) has regularly published the results of the important investigations of himself and his assistants.

The Observatory of the Roman College, Rome: Founded in 1787 by the order of Jesuits, and made celebrated by the labors of DA VICO and SECCHI. Its principal instrument is a FRAUENHOFER refractor of 9.6 inches aperture. Professor TACCHINI, the present director, devotes his attention chiefly to solar spectroscopy. Minor planets are assiduously observed by his coadjutor Professor MILLOSOVICH. It is the central meteorological station of Italy.

The observatories of Naples, Palermo and others, are among the most important in Italy.

Observatory on Etna: In 1880 an observatory was established on Etna 9650 feet above the sea. During the inclement weather of winter the object-glass (only) is removed to Catania, where a duplicate mounting is provided for it.

GREECE.

The Observatory of Athens (founded 1845) remained one of the most active in Europe during the directorship of SCHMIDT (1845—1884.) Here his great map of the moon, six feet in diameter, was constructed from the observations of 20 years.

RUSSIA.

Imperial Observatory of Pulkowa: This observatory, "the astronomical capital of the world" was founded by W. STRUVE in 1839. At his death in 1861, his son, OTTO STRUVE, succeeded him. His grandsons HERMANN and LUDWIG STRUVE are among the corps of observers. The staff consists of the director, four astronomers, four assistants, two computers, a secretary and a number of laborers and workmen. The principal instruments are a 6-inch ERTEL transit, a 6-inch ERTEL vertical circle, a 6-inch REPSOLD meridian-circle, a prime-vertical transit, a 7½-inch MERZ heliometer, a 15-inch MERZ refractor and finally the great 30-inch refractor (objective by ALVAN CLARK, mounting by REPSOLD). The most important and accurate observations of modern astronomy have been made here and are

published in 11 quarto volumes. Besides being the central astronomical observatory, Pulkowa is also the headquarters for the geodetic observations over all Russia.

Observatory of Moscow: Built 1850. The principal instruments are a 10.7 inch refractor and a meridian circle. The late director (TH. BREDICHIN) has made the study of comets a speciality and has formulated a theory by means of which the shape of their tails can be *predicted* in advance in somewhat the same way that their orbits become known after three observations. Ten volumes of *Annals* have been printed in quarto.

The observatories of Helsingfors, Dorpat, Wilna, Warsaw, Kasan, Kieff, and others would deserve special mention in a more extended notice. Many of them are excellently equipped with instruments and observers. Daily photographs of the sun were taken at Wilna from 1869 to 1876.

SWEDEN, NORWAY AND DENMARK.

Observatory of Stockholm: Founded in 1750. Its principal instruments are a 4½-inch ERTEL meridian-circle and a 7-inch REPSOLD refractor. The latter is employed by the director (Professor GYLDEN) to determine the parallax of fixed stars. Very important theoretical investigations are also carried on by Professor GYLDEN. The observations are regularly printed in quarto form.

Observatory of Copenhagen: This observatory is the oldest in Europe, for it was founded in 1641, rebuilt in 1728, 1741, 1780 and again in 1861. The principal instruments of the new observatory are an 11-inch MERZ refractor and a meridian-circle by PISTOR & MARTINS of 4½ inches. The various astronomers who have observed here have made the name of the observatory well known in all civilized countries.

The observatories of Upsala, Lund and Christiania possess refractors of 9 inches, 9½ inches and 7 inches respectively, besides meridian circles etc. At Lund especial attention has been paid to mathematical astronomy by the director (Prof. AXEL MOLLER) and to double stars and stellar spectra by Dr. DUNER. At Upsala Dr. SCHULTZ has made important researches on nebulæ etc.

HOLLAND AND BELGIUM.

Observatory of Leyden: Founded in 1632; a new observatory built in 1860. The chief instruments are a 7-inch refractor by MERZ and a 6.3-inch meridian circle by PISTOR & MARTINS. With the latter instrument extremely accurate positions of the fundamental stars have been established. The Director (V. D. S. BAKHUYSEN) has several assistants. The observations are published in quarto.

Royal Observatory of Brussels: Founded in 1834. In 1877 a 15-inch refractor, by COOKE, and a 6½-inch meridian circle, by REPSOLD, were mounted. Twenty-eight quarto volumes have already been printed.

MEXICO AND SOUTH AMERICA, ETC.

Observatory of Tacubaya (Mexico): Founded in 1880 at Chapultepec; moved to its present position in 1883. Its principal instrument is a 15-inch refractor by GRUBB. The Director (ANGEL ANGIANO) has several assistants. The observations are regularly printed.

Observatory of Cordoba (Argentine Republic): Founded in 1871. During the years 1871–1885 an enormous amount of work was done by the Director (Dr. B. A. GOULD, of Boston) and his assistants. The principal instruments are a 11-inch refractor by FITZ, which can also be used photographically, and a meridian circle by REPSOLD, of five inches aperture. The present Director (Dr. THOME) is engaged in determining the position of every star from the first to the tenth magnitude in the Southern sky.

The Observatory of Rio Janeiro: This institution, founded in 1845, is completely equipped with instruments and has a staff of astronomers.

The Observatory of Santiago de Chili was founded in 1849 by Lieut. GILLISS, U. S. Navy, and rebuilt in 1860 by Dr. MOESTA, the then Director. It possesses a 9½-inch refractor. Little work is now done. Two quarto volumes of observations have been printed.

AFRICA, INDIA, AUSTRALIA, ETC.

Royal Observatory, Cape of Good Hope: Founded in 1820. The successive Astronomers, FALLOWS (1829–1831), T. HENDERSON (1832–1833), T. MACLEAR (1833–1870), E. J. STONE (1870–1879) and DAVID GILL (1879–date) have done work of the first importance in exact astronomy and geodesy, in photography, etc., etc. Very exact determinations of stellar parallax have been made here by HENDERSON and latterly by GILL and ELKIN. A photographic map of the whole southern sky is now being made at the Cape of Good Hope; other extensive operations are in hand. It was near this observatory that Sir JOHN HERSCHEL established his observatory in the years 1834–38. Its principal instruments are a meridian circle of 8-inches aperture, like that at Greenwich, and several small refractors of 7-inches of aperture and less. Its observations are regularly printed in octavo.

Observatory of Madras: This observatory was founded in 1831. Its principal instruments are a meridian circle, and an equatorial by SIMMS, of 8-inch aperture. Much work has been done here by the Director (N. POGSON) and his assistants, but I am not aware of any publications since the eight 4to volumes which cover the observations of the years 1831–1854.

Observatory of Sydney, N. S. W.: Founded in 1855. The principal instruments are a 6-inch SIMMS meridian circle and a 11½-inch

SCHROEDER equatorial. The observatory regularly publishes meteorological and other observations. The Director is Mr. H. C. RUSSELL.

Observatory of Melbourne: Built in 1863. It possesses a great reflector of 4 feet aperture, by GRUBB, which was mounted in 1869, but which has rendered comparatively little service to science. An 8-inch refractor by COOKE and a meridian circle have, however, been very actively and efficiently used, the latter by Mr. WHITE. The results are printed in quarto form.

UNITED STATES.

Dudley Observatory (*Albany*), observatory of Union College: founded in 1851–56. The chief instruments are a 13-inch refractor by FITZ, and a PISTOR & MARTINS' meridian circle of 6 inches aperture. Its directors have been Dr. B. A. GOULD, Professor O. M. MITCHELL, Professor G. W. HOUGH and Professor LEWIS BOSS. There is one assistant. The meridian circle has been vigorously employed in observing a zone of stars for the *Astronomische Gesellschaft* by the present director, Professor BOSS. A railway time service is maintained. Two volumes of observations, etc., have been printed.

Allegheny Observatory, observatory of university of Western Pennsylvania: Founded in 1860. Its principal instruments are a 13-inch FITZ refractor and physical apparatus, such as spectroscopes, bolometers, photometers, etc. An extensive railway time service is maintained. There are two assistants. Under the enlightened direction of Professor LANGLEY, (1860–1887) this observatory became the chief authority in the world on questions relating to solar physics. Its chief financial support has been derived from the liberal gifts of the Hon. WM. THAW, of Pittsburgh.

Amherst College Observatory: Founded in 1857. A 7½-inch refractor by ALVAN CLARK is its chief instrument. Assiduous observations of the satellites of *Jupiter* are kept up here by the director, Professor D. P. TODD.

Annapolis Observatory (U. S. Naval Academy): The observatory has a 7¾-inch CLARK refractor and a 4-inch meridian circle by REPSOLD which latter has become well known through the writings of Professor CHAUVENET, the first director. The observatory is only used for purposes of instruction.

Ann Arbor Observatory—Observatory of University of Michigan: founded in 1854 under Professor BRUENNOW. Its chief instruments are a 12½-inch refractor by FITZ and a 6½-inch PISTOR & MARTINS' meridian circle. Twenty-one asteroids were discovered with this refractor by Professor WATSON, the second director, and the meridian circle has been assiduously used by Mr. SCHAEBERLE (now an astronomer at the Lick observatory) in observations of stars. Professor M. W. HARRINGTON is the present director. He has one assistant.

Harvard College Observatory: This establishment has a most honorable history under the distinguished astronomers who have had it in charge, namely W. C. Bond, G. P. Bond, Joseph Winlock and E. C. Pickering. The principal instruments are a 15-inch Merz refractor (a companion to that of Pulkowa, Russia,) with which G. P. Bond discovered a new satellite to *Saturn*, made extensive studies on this planet, on the nebula of *Orion*, on the great comet of 1858, etc., etc. There are two meridian circles; the largest by Simms has an aperture of 8¼ inches and has done most important work in fixing stellar positions in the hands of Professor W. A. Rogers. A great variety of other work has been done and published here. The last director (Professor E. C. Pickering) wisely turned much of the energy of the establishment into researches in astronomical physics—spectroscopy, photometry and photography. He has determined the brightness of all the lucid stars visible at Cambridge; and his researches on stellar spectra by photography (which are largely carried on with instruments belonging to the late Henry Draper and with funds furnished by his wife, Mrs. Anna Palmer Draper), are among the most important of modern astronomy. The observations are regularly and promptly published in quarto volumes. A time service is kept up. The regular income of the observatory was in the neighborhood of $18,000 before the Boyden Fund of more than $200,000 became available. It is now of course much greater. More than twenty astronomers and assistants are employed here. The whole history of this observatory is an admirable comment on the text that to those who already have and properly use a large instrumental equipment, more should be given. Intending founders of observatories would do well to study the history of this observatory in order to see how comparatively small sums of money placed rightly, will produce relatively great results.

Chicago University, (Observatory of Northwestern University): This observatory was founded in 1862 and purchased the 18½-inch Clark refractor with which Alvan G. Clark discovered the companion to *Sirius*. This telescope long remained the largest and most perfect in the world and many brilliant discoveries were within its reach. It was not fully utilized, however, until Mr. S. W. Burnham (now an astronomer at the Lick Observatory) continued his work on double stars by its means. A 6-inch meridian circle by Repsold is also part of the equipment. The observatory is about to be moved to Evanston, Illinois. Professor G. W. Hough is the present Director. A regular time service has been maintained here by Professor Hough, and physical observations of *Jupiter* and measures of difficult double stars are kept up. There are no assistants.

Cincinnati Observatory, Observatory of University of Cincinnati: Founded in 1842 by Professor O. M. Mitchell. The principal instrument is an 11¼-inch equatorial by Merz, which was assidu-

ously used by Professor O. STONE in double star observations during his directorship. The present Director (Professor J. G. PORTER) has shown what valuable work may be done by small instruments by his catalogue of 4150 southern stars observed with a 3-inch transit. A regular time service is kept up here. The observations are published in six volumes.

Clinton Observatory, Observatory of Hamilton College: Founded in 1855. Its principal instrument is a SPENCER refractor of 13½ inches aperture. This instrument has in the last thirty years been in the hands of Dr. C. H. F. PETERS, who has discovered no less than forty-two minor planets by its means, and made a series of ecliptic charts of the highest value, besides a long series of sun-spot observations and a catalogue of ecliptic stars. This he has done for the most part without assistance.

Georgetown Observatory, (D. C.): Erected 1844. A 6-inch refractor and a small meridian circle are available. The observatory is used for instruction only.

Glasgow Observatory (Missouri): Founded in 1876. Its instruments are a 12¼-inch CLARK refractor and a 6-inch SIMMS meridian circle. Both have been actively used by Professor C. W. PRITCHETT and by his son, Professor H. S. PRITCHETT.

Hanover Observatory (N. H.), Observatory of Dartmouth College: Founded in 1853. The instruments are a 9¼-inch CLARK equatorial, a 4-inch meridian circle, and spectroscopic apparatus with which Professor C. A. YOUNG has done his work on the sun.

Madison Observatory, (Wisconsin), Observatory of the University of Wisconsin: Founded by Governor WASHBURN in 1878. The first director was Professor J. C. WATSON, who died in 1880. The principal instruments are a 15½-inch CLARK refractor, with which Mr. S. W. BURNHAM (now astronomer at the Lick Observatory) made many valuable discoveries and measures of double stars; and a 4.8-inch REPSOLD meridian circle, with which much work was done by the second director (Professor E. S. HOLDEN, now of the Lick Observatory) and the present director (Professor G. C. COMSTOCK), then assistant, and others. The work of 1881–1884 has been printed in four octavo volumes. A fifth volume was printed by Mr. UPDEGRAFF and Miss LAMB, assistants, completing the plan of the first four volumes. An extensive time service is maintained here. A separate student's observatory is attached to the Washburn Observatory, containing a 6-inch CLARK refractor (by means of which Mr. BURNHAM discovered more than 500 double stars) and a 3-inch transit.

New Haven Observatory, Observatory of Yale College: Founded in 1881. It contains a REPSOLD heliometer of 6 inches aperture, one of the most important instruments of the world; an 8-inch Grubb refractor and minor instruments. The heliometer is used by Dr. W. L. ELKIN for determining stellar parallaxes. The observa-

tory extends facilities for testing thermometers and chronometers, and has done much useful work in this direction under Dr. L. WALDO. There are several assistants. This observatory owns a 27-inch flint disc and presumably intends to erect a large refractor at some future time. An extensive time service is kept up.

New York Observatory: The instruments formerly owned (and partly constructed) by Dr. L. M. RUTHERFURD, have been transferred to Columbia College Observatory (Professor J. K. REES, director.) The chief instrument is a 13-inch refractor, whose objective is corrected for the photographic rays. With this instrument Dr. RUTHERFURD made his beautiful photographs of the moon (the best yet made) and many photographs of star clusters, etc., the results of which have not yet been published.

Northfield Observatory, University of Carlton College, Minnesota: Erected 1878. Professor W. W. PAYNE is director and the editor of 7
the *Sidereal Messenger* (8vo, monthly). The principal instruments are an 8¼-inch CLARK refractor and a 4.8-inch REPSOLD meridian circle. An extensive time service is maintained.

Princeton Observatory, Observatory of Princeton College: The student's observatory (erected 1877) has a 9½-inch refractor by 8
CLARK, a 4-inch meridian circle, etc. The Halstead Observatory has a 23-inch CLARK refractor with a CHRISTIE half prism spectro- 9
scope. The director is Professor C. A. YOUNG; the principal assistant is Mr. MCNEILL.

Rochester Observatory, (N. Y.): Erected by H. H. WARNER in 1880. The principal instrument is a 16-inch CLARK refractor. Dr. LEWIS SWIFT, the director, is the discoverer of many comets 10
and has lately found many new nebulæ. Mr. WARNER regularly offers $100 as a prize for each newly discovered comet.

University of Virginia: This observatory contains a 26-inch CLARK 11
refractor with which Professor O. STONE is observing a large list of double stars and nebulæ.

Washington Observatory, U. S. Naval Observatory: The first observations date from 1845. The first staff of observers contained Professors COFFIN, HUBBARD and WALKER among others. The Washington observations from 1845 to 1848 are equal to any printed at that epoch. The methods followed were the German methods of GAUSS and BESSEL, and one of the greatest services of the Washington Observatory to American astronomy has been to set a high standard of excellence, both in theoretical and practical astronomy. COFFIN, HUBBARD and WALKER are the fathers of American astronomy. The director of the observatory from 1844 to 1861 (M. F. MAURY, U. S. N.) turned its activity more and more towards hydrography, and as a result produced his excellent Wind and Current Charts. Astronomy languished, however, till his successor, Lieut. J. M. GILLISS, was appointed in 1861. The older astronomers had in the mean time left the observatory and they were succeeded by a new

school, of which Professors NEWCOMB and HALL were the chiefs, who have maintained the old standard amid many difficulties, and have even added to it. The instruments at present available are a mural circle of 4 inches aperture, a transit of 5.3 inches aperture, a PISTOR & MARTINS' meridian circle of 8½ inches aperture, a MERZ refractor of 9.6 inches aperture, a CLARK refractor of 26 inches aperture, besides photoheliographs and many minor instruments. The staff of the observatory consists of from five to eight officers of the navy, four professors of mathematics, three assistant astronomers, two or three computors, besides workmen and meteorological observers. Fifteen to twenty persons are thus employed in scientific work. An extensive time service is maintained and time balls are dropped at various places. The observatory at Mare Island Navy Yard is a branch of the Naval Observatory. The observations are annually printed in quarto. The large refractor has been actively employed from 1873, when it was mounted, till now. Professors NEWCOMB, HALL and HOLDEN'S observations of the satellites of *Neptune*, *Uranus* and *Saturn* have fixed the masses of the three outer planets. Professor HALL'S discovery of the satellites of *Mars* has given him a new determination of the mass of *Mars* also. Professor HALL has also determined the parallax of several stars with high accuracy, and has measured many difficult double stars. Other miscellaneous work of value has been done with this instrument. The history of the 26-inch refractor during the past 15 years is a complete answer to the question whether large telescopes have been specially useful to astronomy. It is proposed to move the observatory from its present site to one more removed from the smoke and fogs of the city.

Williams College Observatory: This is the oldest existing observatory in America. It was founded in 1836. Under the present director (Professor T. H. SAFFORD) the 4.8-inch REPSOLD meridian circle is actively employed in making a catalogue of polar stars.

OBSERVATORIES IN CALIFORNIA.

In a recent number of the San Francisco *Chronicle* Mr. CHARLES B. HILL, assistant astronomer at the Lick Observatory, printed a short account of various public and private observatories in California. I have somewhat abridged this and have made a few additions, and reprint it here with Mr. HILL'S permission.

DESCRIPTION OF OUR LOCAL OBSERVATORIES.

By C. B. HILL.

"With so formidable a rival as the most extensive astronomical observatory in the whole world to contend against, there exist, nevertheless, in San Francisco and adjacent towns of this State, many private and public observatories which have their own field of usefulness and demand their proper share of attention. For it must not be imagined that the larger telescopes and observatories

make all the discoveries, or even do any more than their proportionate share of research. The Lick Observatory itself has all its reputation yet to make to justify the expectations formed, and that it will succeed in this, is not doubted. At the same time the astronomical work, upon which, as Professor HOLDEN himself says, "the good name of the observatory entirely depends," is yet barely commenced; while several of the less widely known observatories of this coast to be described in this article have been for some time doing good work, either in the way of study or public instruction.

It would be but a fair recognition to give the first position in the list to what was doubtless the pioneer institution of California, although itself of quite recent construction.

THE DAVIDSON OBSERVATORY.

The instrumental outfit here consists of a 6.4-inch CLARK object-glass, equatorially mounted, which is the private property of Professor GEORGE DAVIDSON of the United States Coast and Geodetic Survey. The telescope is placed in a convenient portable observatory, situated within the inclosure at the junction of Clay and Octavia streets, San Francisco, and devoted, by act of the Supervisors, to the use of the Coast and Geodetic Survey as the standard telegraphic longitude station of the Pacific coast. The neat picket-fence inclosure bears on the door the legend "United States Coast and Geodetic Survey, Lafayette Park Astronomical and Telegraph Longitude Station, San Francisco, 1880;" and above this a separate sign indicating the "Davidson Observatory." The dome-shaped building contains Professor DAVIDSON'S equatorial, and the other portable observatories protect the time, latitude, gravity and magnetic instruments belonging to the United States Coast and Geodetic Survey.

A great deal of fruitful investigation has been carried on by means of this small equatorial. The telescope with its present FAUTH mounting was exhibited by the maker at the Centennial where it obtained a gold medal, and whence it was brought to this city by Professor DAVIDSON. He has had the telescope and its mounting, with the portable observatory, at the summit of Santa Lucia mountain (5,960 feet) in Monterey county, where it was taken to observe the total solar eclipse of January 11, 1880. The solar eclipses of 1883 and 1886 were observed at the present location. In 1882 while DAVIDSON was in New Mexico in charge of the United States Transit of Venus party, he gave assistant GILBERT of the Coast Survey the use of his private observatory, and the second of the only two "transits" visible during this century and the next was successfully observed with the DAVIDSON equatorial, and with other smaller telescopes at the same place. Some close investigation of the planet *Saturn* during the opposition of 1884—85, when the rings were at the widest opening,

has been published in the proceedings of the California Academy of Sciences by Professor DAVIDSON. A detailed drawing of *Saturn*, fifteen inches in diameter, has been for some time in the hands of BRITTON & REY for reproduction by the photogravure process. Besides this he has made many drawings of *Jupiter* and *Mars*. In addition to this work a large number of observations of star occultations and comet positions have been made and published in the proceedings of the Royal Astronomical Society, London, the *Sidereal Messenger*, Minnesota, and in the bulletins of the California Academy of Sciences. Classes from the High Schools have also been permitted to use the observatory.

THE CHABOT OBSERVATORY.

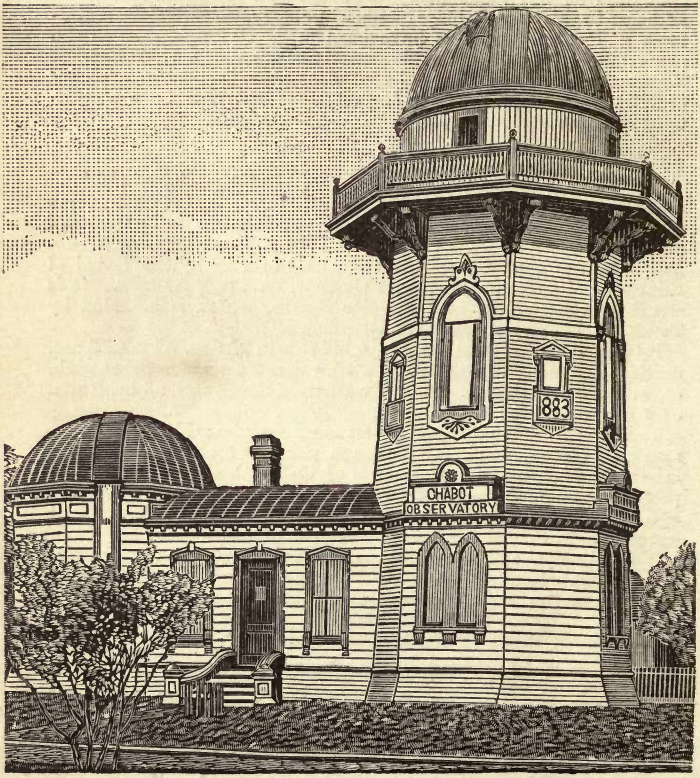
In the center of one of the public squares of the city of Oakland stands a neat frame structure which will for many years to come serve as a most fitting monument to the intelligence and public zeal of one of her citizens. The CHABOT Observatory was donated to the city of Oakland, to be held in trust by the Board of Education, by the late ANTHONY CHABOT, in the year 1883. It is situated in the middle of Lafayette square, which is bounded by Tenth, Eleventh, Jefferson and Grove streets.

Its exact geographical position is in latitute 37 deg. 48 min. 5 sec. north; longitude 122 deg. 16. min. 34.4 sec. west from Greenwich, or, in time, 8 hr. 9 min. 6.3 sec. west from Greenwich; 3 hr. 0 min. 54.2 sec. west from Washington.

The active existence of the observatory may be said to have commenced in May, 1886, for although prior to that the then Superintendent of Schools, J. C. GILSON of Oakland, spent much of his private and official time in the establishment of the observatory, etc., still it was not until the present director, FRED. M. CAMPBELL, took charge of the School Department that assistant astronomers were appointed and tl e observatory opened to the public on four evenings of each week. Of the other two nights, each Monday night is reserved to the High School classes and Friday is occupied with observations by the two assistants to correct the clocks which furnish the official time to the city of Oakland.

In a pamphlet published by the Oakland School Department Mr. CAMPBELL has said :

"It may not have occurred before to those who read this article that in no other city in the world is there an astronomical observatory devoted to the public instruction, and more particularly to the public school education; but this is undoubtedly the case, and the fact would be well appreciated by non-professional students in many other cities in this and transatlantic countries, where the many and magnificently equipped observatories are so closely and entirely devoted to the grand problems of astronomical research that the admission of some private student of the science with no



THE CHABOT OBSERVATORY—OAKLAND, CAL.

facilities of his own is only acquired as a rare privilege upon stated occasions. Of course, all the great colleges and universities possess attached observatories, but these are entirely devoted to their special uses, whereas the open sesame of the CHABOT Observatory is a card obtained at the office of the Superintendent of Schools, to receive which are only needed a formal application and a proper appreciation of the privilege."

The outfit of the CHABOT Observatory consists of an eight-inch equatorial telescope, with circles, driving-clock, spectroscope, micrometer, and all necessary accessories; a 4½-inch transit, a sidereal clock, chronometer, mean-time clock, chronograph, and valuable meteorological instruments, all of the most modern and approved construction. There is a small library and a very desirable collection of maps, photographs and engravings to illustrate different features to the visitors.

Mr. CAMPBELL has thoroughly succeeded in carrying out the broad ideas of the projector. The institution is decidedly popular, and the available evenings are invariably engaged for over two months in advance. Every day at 12h. of 120th meridian (Pacific standard time) the City Hall bell is struck three times by automatic signal from the CHABOT Observatory; beyond this duty there is very little time for astronomical work. A few observations have been printed in the *Sidereal Messenger.*

The assistant astronomers are CHARLES BURCKHALTER of Oakland and CHARLES B. HILL (now assistant astronomer at the LICK Observatory). The citizens of San Francisco and Oakland and Eastern visitors receive cards of admission in order of application and without favor, and every clear night a party of from eight to twelve persons is shown all the principal and characteristic objects in view at the time and listens to the explanations of the astronomers in charge.

Mr. CHABOT'S will left a bequest of $10,000 to the observatory. It has not been decided how this shall be spent. Possibly a reflecting telescope of 15 inches aperture will be added to the equipment.

PRIVATE OBSERVATORY OF MR. BURCKHALTER.

Before becoming attached to the CHABOT observatory Mr. BURCKHALTER had erected at his own home, on Chester street, West Oakland, au observatory which is a model of its kind. His equipment consists of a 10½-inch reflecting telescope by BRASHEAR of Pittsburg, Pa. This fine instrument, with its outfit of eye-pieces, prisms and spectroscope, is equatorially mounted on a solid brick pier in a commodious and very convenient building, with revolving dome, etc., and is supplemented by a small transit instrument, with sidereal clock, etc., in an adjoining building. The transit has one and five-eighths inches clear aperture and is also mounted on a brick pier.

One of the most interesting facts in connection with this observ-

atory, and the proudest feature about it to the owner, is that all the mechanical work, the masonry and carpentering, and even the delicate clockwork for the equatorial movement, has been done by Mr. BURCKHALTER himself, in the limited time he has been able to devote to this purpose during an active business life.

After obtaining the speculum the necessary flat, and the optical arrangements from Mr. BRASHEAR, Mr. BURCKHALTER had the necessary castings made from his own drawings, and completed every detail for the equatorial with his own hands. The mirror is a fine one. Mr. BURCKHALTER'S reflector is a first-class specimen of the maker's skill and in power is equal to, if not slightly greater than, the $8\frac{1}{2}$-inch refractor of the CHABOT observatory.

THE BLINN OBSERVATORY.

The reference to the astronomical establishments of Oakland would be far from complete without mention of the private observatory of F. G. BLINN, at Highland Park, East Oakland. His observatory consists of two adjoining rooms, like Mr. BURCKHALTER'S. The larger room contains a 5-inch CLARK achromatic, equatorially mounted, with circles, slow-motion and an effective battery of eyepieces. The annexed apartment is for the protection of his $1\frac{3}{4}$-inch LATIMER-CLARK transit, with a mean-time clock and a sideral clock, thus giving him very complete and reliable means for determining and keeping his local time for special observations. From his location there may be obtained on an extraordinarily clear day a first-class view of the three peaks of Mount Hamilton and the Lick observatory. Mr. BLINN is also an effective mechanic, and designed and constructed a great portion of his observatory. He is quite interested in telescopic comets, and rarely fails to examine the latest cometary discoveries of the "professional" astronmers.

THE STUDENTS' OBSERVATORY.

This is connected with the University of California and is under the direction of Professor FRANK SOULE of the university. The Lick observatory on Mount Hamilton is under the control of the Board of Regents of the University of California, and is styled the "Lick Astronomical Department" of that college; but, as intended by the donor, its aim is principally that of a great laboratory of astronomical research and study, where graduates of the scientific department may be received for a higher course after completing the elementary astronomical work. This duty of purely scientific investigation is the function of every great observatory attached to the larger colleges, as for example the Harvard College observatory and those of Princeton, Michigan and the University of Virginia, in this country, the Cambridge University and numerous other colleges in Europe. About four years ago, an appropriation of $10,000 was obtained from the

Legislature, out of which a "Students' Astronomical Observatory" has been constructed and equipped under Professor Soule's care. The following instruments have been purchased: From Fauth & Co., of Washington, a 6-inch equatorial refractor, with a Byrne objective, having a cast-iron pier, solar eye-piece, micrometer eye-pieces, driving clock and mountings complete, a spectroscope, with Rowland's gratings; a Davidson combination transit-and-zenith telescope of three inches aperture, complete; an electro-chronograph; a first-class sidereal chronometer, with electric break-circuit attachment, from Negus Brothers, of New York; and a first-class astronomical clock, from the Howard Watch and Clock Company of Boston. To the chronograph and clock are attached the electric connections necessary to determine longitude by the telegraphic method.

The building is picturesquely situated on a rise a short distance northwest of the main buildings of the university, near rolling ground and surrounded by foliage. There are five rooms, including the equatorial room, transit room, library and office, sleeping-room, and an apartment for the earthquake registers (of which there are three), known as the seismograph house.

This observatory affords opportunity for practical application of the principles of geodesy as taught in the class-room, and enables students in engineering to acquire facility in the astronomical determination of time, latitude, longitude, etc., as required in extended surveys, navigation and practical astronomy.

The equatorial and the spectroscope furnish means for prosecuting studies in solar physics and similar fields of investigation. One room in the observatory is provided with a set of meteorological instruments, comprising maximum and minimum thermometers, two of Green's barometers, a Draper thermograph, hygrometer, anemometer, etc., and observations are regularly taken, recorded and forwarded to the United States Signal Service Office in San Francisco.

OBSERVATORY OF THE UNIVERSITY OF THE PACIFIC.

The above-named college, situated in San José, has lately, through the liberality of Captain Charles Goodall, of San Francisco and David Jacks, Esq., of Monterey, been well equipped with a small telescope and working observatory. The outfit, for which these two gentlemen each subscribed equally, comprises a 6-inch 16
Clark equatorial, a 3-inch Davidson meridian instrument, manufactured by Fauth & Co., and a sidereal chronometer; all properly mounted and protected by a neat and practical observatory building, with dome for the large telescope in the center, and the reception-room and transit-room on either side. Rev. Dr. A. C. Hirst is president of this college and Professor T. C. George has charge of the observatory and the science department.

MILLS COLLEGE OBSERVATORY.

Still another educational institution of California is provided with facilities for the study of astronomy. The observatory building is finished but it is not yet completely equipped. A good 5-inch telescope has been mounted in the dome, and before long it is expected to have a transit and other accessories of a working observatory.

From the foregoing it is seen that, including the Lick Observatory, there are eight astronomical observatories in this State, the seven smaller ones being all located in the cities and towns on either side of San Francisco bay. These, with location, aperture of principal telescopes and the geographical positions, are enumerated in the following table :

ASTRONOMICAL OBSERVATORIES OF THE PACIFIC COAST.

Lick Observatory of the University of California, Mount Hamilton—Three telescopes, 36-inch, 12-inch and 6-inch ; all refracting. Position, 37 deg. 20. min. 24 sec. north latitude ; 121 deg. 38 min. 35 sec. west longitude.

Chabot Observatory, Oakland—Telescope, 8½-inch ; refracting. Position, 37 deg. 48 min. 5 sec. north latitude ; 122 deg. 16 min. 34 sec. west longitude.

Davidson Observatory, San Francisco—Telescope, 6½-inch ; refracting. Position, 37 deg. 47 min. 24 sec. north latitude ; 122 deg. 25 min. 40 sec. west longitude.

Burckhalter Observatory, Oakland—Telescope, 10½-inch ; refracting. Position, 37 deg. 48 min. 22 sec. north latitude ; 122 deg. 17 min. 37 sec. west longitude.

Blinn Observatory, Oakland—Telescope, 5-inch ; refracting. Position, 37 deg. 47 min. 37 sec. north latitude ; 122 deg. 14 min. 7 sec. west longitude.

Students' Observatory of the University of California, Berkeley—Telescope, 6-inch ; refracting. Position, 37 deg. 52 min. 21 sec. north latitude ; 122 deg. 15 min. 37 sec. west longitude.

University of the Pacific, San José—Telescope, 6-inch ; refracting. Position, undetermined,

Mills College, Brooklyn—Telescope, 5-inch ; refracting. Position, 37 deg. 46 min. 44 sec. north latitude ; 122 deg. 10 min. 50 sec. west longitude.

Elevation above the sea—Lick, 4,209 feet ; Davidson, 373 feet ; University, 320 feet, and Blinn's 159 feet.

To these should be added the observatory at Mare Island Navy Yard, where the time is daily determined and from which the time ball on Telegraph Hill is dropped by an automatic signal.

Besides the more pretentious establishments there are several fair or average astronomical glasses in the possession of gentlemen

interested in the science, some of excellent power and definition. Captain CHARLES GOODALL, on McAllister street, in San Francisco, has an excellent CLARK achromatic, of 5 inches aperture, Dr. J. H. WYTHE, of Oakland, has an 8½-inch BRASHEAR reflector and Dr. JAMES MURPHY, of San Francisco, a fine 4-inch achromatic; St. Matthew's Hall College, San Mateo county, Cal., has an 8½-inch BRASHEAR mirror permanently mounted, with observatory building, etc., but without transit instrument; Santa Clara College is provided with a suitable telescope, as is also the Boys' High School, of San Francisco. The last-mentioned instrument, of 3½ inches aperture, was used by the present writer, through the kind permission of the proper authorities, to observe the transit of Venus in 1882. It is reported that Principal REID'S Belmont school will, before long, be provided with a telescope and accompanying observatory. The Raymond Hotel, Pasadena, has a 4 inch CLARK telescope.

Any interesting occurrence taking place in the heavens is watched, say at Greenwich, until daybreak puts an end to the observation. Farther west day has not yet commenced, and study of the occurrence may be continued until, say at Washington, five hours' additional time has been gained; and so on, still farther west, three hours more to San Francisco, and then the Pacific ocean intervenes, and nothing can be done until the great observatories of Adelaide and Melbourne can commence observations, six and one half hours of longitude having been lost in the mean time. It is plain, therefore, that for several hours on each night this object, whatever it may be, will be in view of the California observatories when no other telescopes in the world will be available for the examination required."

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